Aerotherm Project 7122

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# EV SPACE SUIT GLOVES (PASSIVE)

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## FOREWORD

This report covers the development of a pair of thermal gloves by Aerotherm, Division of Acurex Corporation, for the National Aeronautics and Space Administration, Johnson Space Center under contract NAS9-14461. The program manager and the project engineer were Mssrs. William Elkins and Glenn Tickner respectively.

The authors would like to acknowledge the assistance and cooperation of Mr. Joseph Kosmo, the program technical monitor, and Dr. Frederick Dawn of NASA throughout this program. The authors further would like to acknowledge the capable assistance of Mrs. Marge Lovell and Mr. Robert Alesna for glove fabrication, and Mr. William Staiger for glove design.

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## INTRODUCTION

One of the most critical elements in an Extravehicular Suit (EV) Assembly is the pressure and thermal glove assembly. No single component of the suit has more influence on the efficiency with which an EV task can be accomplished.

On December 3, 1974, Aerotherm Division of Acurex Corporation was awarded a contract to design, develop, fabricate, and test the thermal insulating overglove. The thermal glove was to be integrated with government furnished pressure gloves. This final report covers all aspects of the completed program

Highlights of the thermal glove program are:

- The design features extensive use of Nomex felt materials in lieu of the multiple layer insulation formerly used in the Apollo thermal glove. Felts are more efficient thermal insulators under compressive loads and are easier to use in fabrication.
- Thorough thermal analysis and testing were accomplished in support of candidate design selection and detail design requirements.
- Tactility, glove life, and thermal protection goals were met by the thermal glove design developed under this program. Mobility of the basic pressure glove was degraded to a greater degree than desirable.

As the result of this program, recommendations are made which, if implemented, will result in a significant improvement in mobility, reliability, and a reduction in cost not only for thermal gloves but for the entire thermal overgarment ensemble.

The program was started by first designing, fabricating, and testing, one right hand glove referred to as Glove I. The testing included a man 100,000 cycles test. Information gained from Glove I design, fabrication, and testing was incorporated inthe design of the delivered pair of gloves known as Gloves IA. These final pair of gloves were exposed to the identical tests except for life cycling. The left hand glove of the delivered pair is shown in Figure 1-1, and schematic showing the layup is presented in Figure 1-2.

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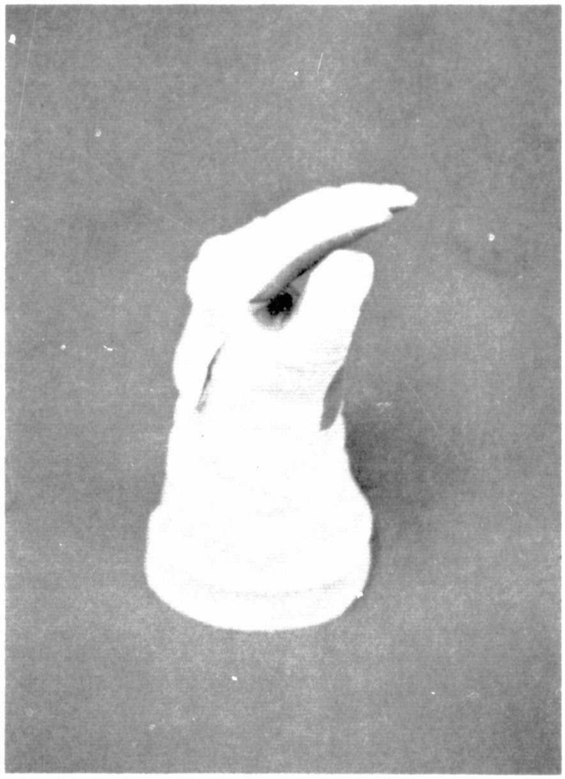



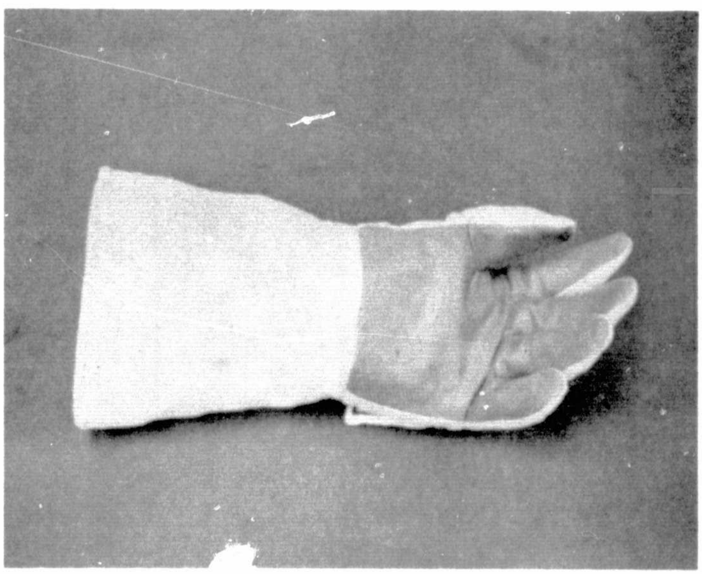

Figure 1-1. EV thermal glove IA.

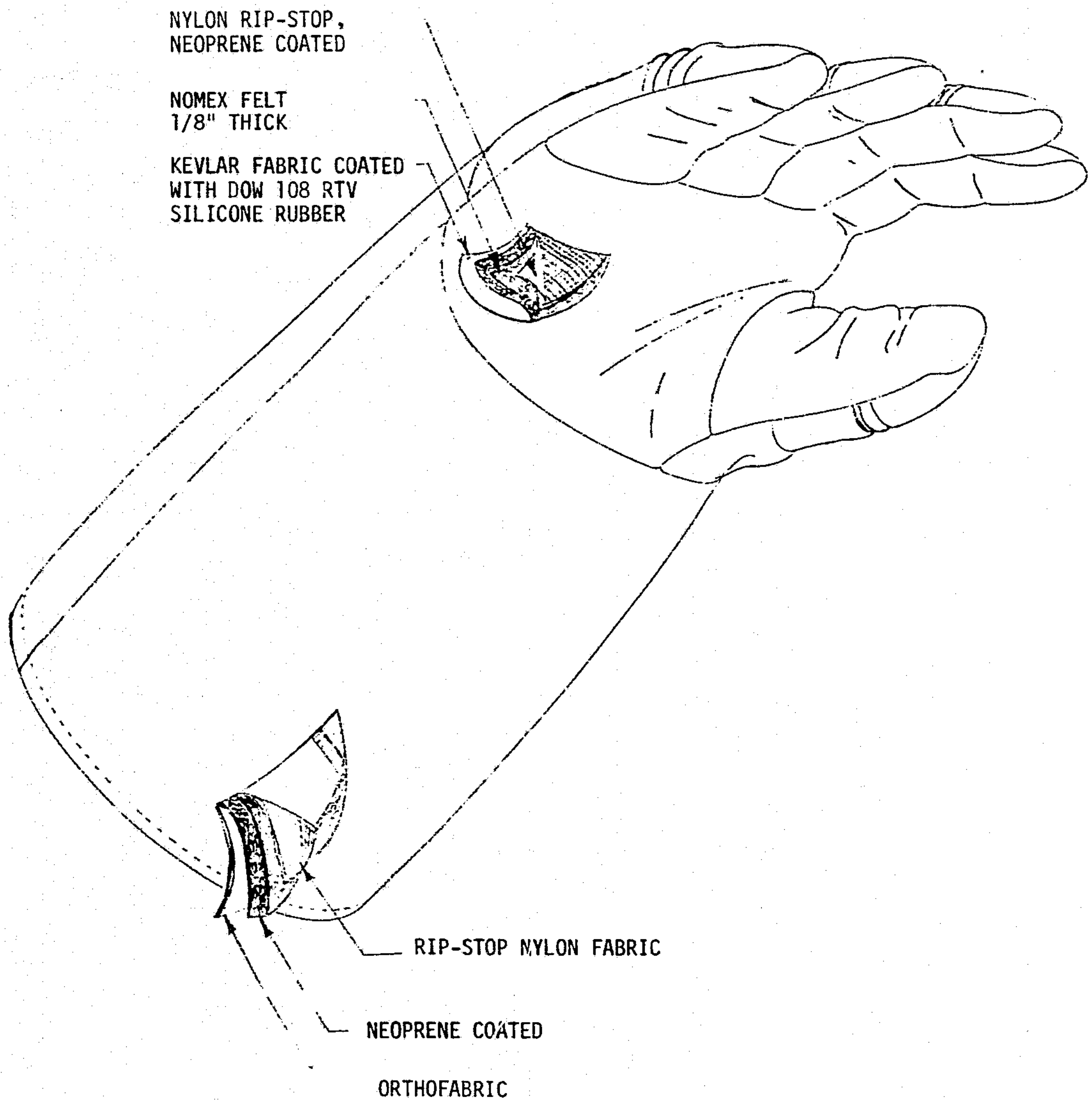


Figure 1-2. Schematic layup of thermal glove.

## SECTION 2

## OBJECTIVE

The primary objective of the EV Thermal Protective Glove program was to design a thermal protective glove whose protective capabilities and performance characteristics exceeded those of the A7LB Skylab gloves. Since thermal gloves are worn by astronauts during extra - vehicular activity (EVA) in orbital flight, glove mobility, tactility, and comfort were of concern in the design. Mobility, tactility, and thermal tests were performed to verify that the end item product, a pair of thermal protective gloves, satisfied the requirements.

## SECTION 3

## TECHNICAL DISCUSSION

This section discusses the technical work performed to design and fabricate one pair of EV thermal protective space suit gloves. It starts with the basic design constraints and then discusses design concepts envisioned at the beginning of the study. Additionally, the analyses, final design, material selection, safety, and quality assurance efforts are reviewed.

### 3.1 DESIGN CONSIDERATIONS

Design conditions are dictated by the expected use of the glove during a mission and the system requirements. These items are discussed in detail in the Mission Constraint and System Requirements document (Reference 1). The salient points are reviewed in the following sections.

#### 3.1.1 Design Constraints

The thermal protective gloves are used in a high vacuum space environment and under extreme abrasive conditions. These gloves are designed to withstand 100,000 manned cycles without degrading the performance of the thermal glove or the underlying pressure glove.

The thermal gloves were to be designed to grasp a 3.8 cm (1-1/2 inch) diameter, 5.4 Kg (12 pound) metal rod at temperatures of +93.3°C (+200°F) and -129°C (-200°F) for a period of 3 minutes at orbital altitudes. The maximum and minimum innermost surface temperature of pressure glove were limited to 43.3°C (110°F) and 10°C (50°F) for the two respective outer surface temperatures.

The thermal glove should be seperable from the pressure glove to permit repair or replacement of either. Hence, the design of a thermal glove should include a means of attachment without seriously degrading glove tactility or mobility.

#### 3.1.2 Mission Constraints and System Requirements

The details of the mission constraints and system requirements are discussed in Reference 1. The glove is designed for the following four environmental conditions:

- Thermal
- Barometric
- Physical
- Micrometeoroid

In addition to the thermal requirements discussed in Section 3.1.1, the glove is designed to be worn by an astronaut for a maximum period of 8 hours which includes 1 hour of pre- and post-EV preparation.

The glove must interface with satellite equipment, spacesuits and particularly the government furnished pressure glove. An astronaut wearing both the pressure glove and the thermal glove must be able to operate all controls, latches, hand holds, and other objects associated with the interior and exterior of the vehicle and the air lock. Further, during a mission, the astronaut must be able to handle basic tools to perform his assigned tasks.

## 3.2 DESIGN CONCEPT

A number of design concepts were envisioned as solutions to the basic thermal glove design problem. The various design candidates centered around fitting the government furnished pressure glove and meeting the specific design and mission constraints and systems requirements discussed earlier. The requirement of independent fabrication of thermal glove from the pressure glove was a major factor considered in the final selection of the design concept.

A matrix of designs was reduced to three concepts with several variations of each. These were classified as:

1. Integral glove.
2. Moulded glove.
3. Fabric layup (shell) glove.
   - The integral glove concept featured tying the thermal glove directly to the pressure glove by combining the seams. This design provided maximum union between the two gloves yielding good tactility and transfer of shear and normal forces to the hand. However, it would have been exceedingly difficult to fabricate, because it would have required reworking the GFE pressure glove to reseam the thermal glove into it.
   - The moulded glove concept would be developed on a special tool which represents the finger and thumb assembly of the pressurized glove. The tool would be dipped

in a silastic type solution to form the inner layer. The primary insulators, MLI and felt would be laid into position as the glove is built up. The final assembly would be coated to provide a tight, seamless glove assembly over the finger areas. This method would have required special tooling, but it would provide a seamless finger assembly which would reduce the number of potential leek pathes. It was expected to be very time consuming to learn the proper techniques to lay in the MLI into the assembly.

- The fabric layup technique would consist of fabricating two separate fabric gloves (an inner shell and an outer shell) with the primary insulator (middle shell) placed between the two. The pattern which comprises the fingers would be constructed by a retangular development or a near circular development. The rectangular cross section would reflect four seams joining the two vertical sides and two horizontal sides of the fingers. The resulting pattern developments would be greatly simplified. However, the four seams cause increased areas of potential thermal shorts, increased potential interference between fingers, and increased bending moments. The near circular cross section development would essentially have one slightly curved bottom pattern covering the base of each finger. The top of the finger would form a semicircle around the bottom pattern completing a near circle around each finger. The curved upper section would easily house the MLI and the bottom section would be well suited for felt. This particular shape would be more difficult to pattern than the rectangular development. However, it would have half the total numbers of seams thus minimizing the disadvantages cited above. One difficulty with this approach would be to physically tie all three layers together while maintaining good glove tactility and mobility.

The matrix of design concepts was evaluated for a number of design criteria before a final selection. A tradeoff analysis was performed which included the following factors:

- Ease of fabrication
- Thermal protection
- Micrometeoroid protection
- Abrasion resistance

- Mobility
- Tactility
- Usage
- Safety
- Aesthetics
- Available funds and time.

After weighing all these factors, the fabric layup technique was decided upon. This approach seemed to provide the least risk and the highest probability of achieving the desired physical and thermal characteristics.

For the purposes of the following discussion, the actual glove design is considered as consisting of three shells: The inner shell (the layer closest to the pressure glove), the insulative shell (middle shell), and the outer shell. In order to clarify our discussion, each shell will be discussed separately in the following sections.

Inner Shell

Requirements

The requirements for the inner shell identified include the following:

- Nonpermeable — In order to obtain minimal thicknesses of the insulator and maintain a low profile of the thermal glove, the insulators were to be sized for orbital atmospheric pressures. The effective thermal conductivity of insulators decreases significantly with ambient pressure. Thermal conductivity can be lost when the pressure glove leaks and bleeds through the inner shell into the insulation; hence the inner shell should be nonpermeable. For this case, the gases collect between the inner shell and the pressure glove, flow out the gauntlet and do not alter the effective thermal conductivity of the insulators.
- Ease of Fabrication — Minimizing cost of fabrication was a major design goal. Consequently, materials which could be easily handled were favored over more exotic and difficult-to-handle materials.
- Abrasion Resistance — There could be some slight relative motion between the pressure glove and the inner shell. Further, the inner shell could undergo many flexures during its usable life. Hence, the materials used to make up and unite the inner shell must be high in abrasion resistance.

- Friction — Friction will minimize the relative motion between the inner shell and the pressure glove and prolong the life of both the pressure glove and the thermal glove. Hence, the material of the inner glove should have a friction coating. This coating can serve as the nonpermeable layer discussed earlier.
- Flexibility — All materials in the pressure glove must be able to tolerate a large number of flexures, particularly for areas around the joints. The material selected must be able to tolerate these flexures throughout the temperature range the materials will encounter in space operations.

Applicable Areas

In that all areas of the inner glove require the same common factors, it was recommended that the entire inner shell be fabricated from the same material with the friction layer/nonpermeable coating located on the pressure glove side. Further, all stitches and seams would be coated to prevent gas leakage into the outer shells.

## Middle (Insulative) Shell

The regional requirements vary. Hence, each region will be discussed separately in this section.

### Anterior Aspect (Palm and Fingers)

The insulative layer must provide thermal protection for the hot/cold bar test, be flexible to maintain adequate glove mobility and transfer tactile information.

Requirements:

- Compressibility — Gripping the bar can cause pressure loading up to 34,000 N/m$^2$ (5 psi) and thereby reduce its thermal insulative characteristics. The material selected must be relatively stiff so that thermal protection is not seriously de-degraded. Stiffer materials, however, decrease tactility and mobility.
- Flexibility — The fingers must be flexed with only a 10 percent degradation loss in glove mobility. Hence, the insulative shell must be flexible.
- Thermal Insulation — The thermal insulator must be selected to protect the hand for the various thermal design conditions.
- Ease of Fabrication — The thermal insulator should be easily incorporated into the glove and not pose serious fabrication problems.

Dorsal Aspect (Fingers)

Requirements:

- Flexibility — The dorsal aspect of the fingers experience considerable amount of flexure. Unlike the opposite side, it is not required to tolerate compressive loads. Hence, multilayer insulation (MLI), if unloaded, is quite acceptable. MLI provides excellent flexibility and thermal protection.
- Thermal Insulation — The insulative shell must protect the hand from incident solar flux for the hot case and from radiation to space for the cold clase. Minimal number of layers of MLI were recommended to maintain a low glove profile.
- Ease of Fabrication — Although MLI layup is not as easy to fabricate as felt, we are dealing with only three layers which does not pose a serious problem in fabrication.

Dorsal Aspect — Access Flap for Pressure Glove Palm Restraint Strap

Requirements:

- Locking Mechanism — The access flap must be secured to the gauntlet.
- Flexibility — The locking mechanism employed will restrict the flexibility of the flap. However, this was not considered a problem because this area is relatively immobile. The insulator used in the flap must be flexible enough so as not to increase the stiffness of the glove in this area.
- Thermal Protection — The primary insulator must protect the hand from the same environment as discussed for the dorsal phalanges.

Gauntlet

Requirements:

- Thermal Protection — The thermal glove must provide thermal protection from the incident solar radiation and from surface radiation to space. This can be accomplished with low density felt or MLI.
- Fabrication — Simplified fabrication techniques can decrease glove costs.

Outer Shell

Anterior Aspect (Fingers and Palm)

Requirements:

- Flexibility and Strength — The outer shell represents the working surface of the glove. This surface material must possess high strength and tear resistance and be able to tolerate many flexures without fabric failure for a wide range of operating temperatures 93 to -129°C (±200°F).
- Friction Coating — This surface will be used extensively to handle tools. Hence the outer fabric must be coated with a high friction coating. This coating must be able to tolerate the operating temperatures without becoming too soft, hard, or brittle. Further, the fabric being coated must be amenable to this coating.
- Abrasion — The outer shell (material and thread) must possess high abrasion resistance characteristics.
- Optical Properties — Optical properties are not important in this portion of the glove.

Dorsal Aspect and Gauntlet

Regional Requirement:

Other than the anterior aspect of the glove, all other surfaces possess the same requirements. Hence, they are considered together.

Requirements:

- Coloring — The dorsal and gauntlet region constitutes about 80 percent of the glove-gauntlet surface area. A white or near white color favored because of preferred aesthetics.
- High Tear and Snag Resistance — In that the glove during normal use will encounter various sharp objects which may tear or snag the outer fabric of the glove, a material which has high tear and snag resistance will be selected.
- High Abrasion Resistance — Normal usage will continually wear the fabric. High abrasion resistance will prolong the life of the glove.
- Optical Properties — It is desirable to choose a fabric which is a good radiation emittor and reflector so that incident radiant flux can be reradiated and reflected to space.

- Fabrication — Materials which can be fashioned with minimal effort are preferred to minimize costs.

## 3.3 ANALYSIS

Before final design could be completed, it was necessary to examine various technical problems encountered. Factors such as heat transfer, micrometeoroid protection and material characteristics had to be considered before completing the design. The technical details involved in the analysis are presented in the following sections.

### 3.3.1 Materials Analysis

This section will review the analysis conducted in establishing the data from which final glove materials selections were made (described in Section 3.4). The material analysis was conducted in parallel with the thermal and micrometeoroid analyses and provided basic data for those studies. Additionally, the overall design objectives including maximum mobility, tactility, and durability were considered in this analysis.

Initially, this section will present the results of the materials studies. Secondly, the results of the in-house tests performed on felts, and lastly, the work conducted in evaluation of alternate palm coatings and neoprene thread sealant will be presented.

Concept Evaluation

Initially a detailed review was conducted to establish broad categories of materials which could potentially satisfy the requirements of the various glove elements. The first portion of this review included a literature survey. The primary data source included in this survey was JSC 02681, Nonmetallic Materials Design Guidelines and Test Data Handbook (Reference 2). This was followed by review of other data sources including the NASA Monthly Progress Report on Development of an Inexpensive, Lightweight Thermal Micrometeoroid Garment for Space Suits, NASA Star Index (Reference 3) etc. The result was the identification of an extensive series of materials for potential consideration. The common element in this initial search was for materials which had prior use or consideration for directly similar applications by NASA.

Concurrent with this literature survey, contact was established with a wide range of suppliers. The suppliers included filament manufacturers, textile fabricators (weavers, knitters, etc.), resin and elastomer formulators, and related manufacturers. The supplier survey provided identification of potential sources and an early assessment as to the availability of the respective materials.

From the aforementioned literature and industry surveys, an initial materials listing was generated. Table 3-1 presents a summary of the different material systems considered in this initial work and the respective properties considered. Table 3-1 also includes the potential glove elements of interest for each material group. This initial listing served as a basis for preliminary comparison between candidates and for identification of desirable properties.

Subsequent to this listing, data were accumulated for each material and samples were obtained. These samples were then evaluated on a qualitative basis where samples were used alone or with laboratory prepared glove element subsections. These tests permitted laboratory personnel to handle and evaluate various materials; those materials not offering potential benefit were eliminated.

Evaluation of potential approaches for an effective thermal insulator provided the most challenging problem in the glove material analysis because it must be integrated with other design constraints. For example, an extremely thick felt would solve the thermal insulation problem, but would generate a tactility and mobility problem. Hence, trade-offs are required to optimize the design.

Two basic approaches were identified as possible solutions to the thermal insulation problem. The approaches considered, together with the various material types incorporated within each approach are summarized in Table 3-2.

MLI

Multilayer insulators (MLI) are highly flexible. Further they have a history of usage for space type missions by NASA. However, conductance data on aluminized mylar interleafed with a lightweight polyester scrim, indicated decreased conductance (degraded performance) under applied loads. Further MLI is fragile and difficult to work with when laying it into small areas. It is considered acceptable in all areas of the glove except the tactile surfaces.

Foams

A number of concerns arose when considering foams. These concerns included the lack of an open cell silicone foam and the potential low temperature rigidity of other available open cell foams. An open cell structure is considered desirable from a conductivity standpoint at reduced pressures when convective transport and gaseous conduction mechanisms are removed. Open cells are required to avoid cell expansion when placed in a vacuum. It was concluded that foams would not offer adequate thermal protection under compression required for the glove.

TABLE 3-1. INITIAL MATERIAL INVESTIGATION SUMMARY

| Material System and Type | Properties Considered | Potential Glove Elements |
|---|---|---|
| Polymer Films | | |
| Polytetrafluoroethylene (Teflon) — FEP | Flammability | Multilayer Insulation |
| Polyester (Mylar Types A and T) | Strength | |
| Polyimide (Kapton Types F and H) | Ultraviolet Resistance/Transmittance | |
| | Thermal Conductivity | |
| | Specific Heat | |
| | Frictional Behavior | |
| | Available Thickness | |
| Foams | | |
| Polyethylene | Thermal Conductivity | Thermal Insulation MLI Separators |
| Polyurethane | Density Ranges Available | |
| Polyvinyl Chloride | Open/Closed Cell Availability | |
| Polypropylene | Flammability | |
| Urea-Formaldehyde | Compression Behavior | |
| Silicone | Ultraviolet Radiation Resistance | |
| Felts and Batts | | |
| Aramid (Kevlar) | Thermal Conductivity | Thermal Insulation |
| Wool | Flammability | |
| Polyimide | Available Thickness | |
| Dacron | Compression Strength | |
| Polyamide (Nylon) | Densities Available | |
| Nylon Viscose | Presence of Binder | |
| Polypnopylene | | |
| Polytetrafluoroethylene | | |
| Polyamide (Nomex) | | |
| Ceramic (Zirconia-Refrasil) | | |

TABLE 3-1. (CONCLUDED)

| Material System and Type | Properties Considered | Potential Glove Elements |
|---|---|---|
| Filaments Yarns | | |
| Aramid (Kevlar 49 and 29) | Strength | Outer Shell, Inner Shell, Gauntlet, and/or Palm Fabrics, Threads |
| Nomex | Flammability | |
| Eglass | Thermal Conductivity | |
| Beta Glass | Specific Heat | |
| Polytetrafluoroethylene (Teflon-TFE/ Goretex) | Abrasion | |
| Nylon | Denier Availability | |
| Polyester (High Tenacity) | | |
| Polyacrylinitrile | | |
| Modacrylic | | |
| Novoloid (Kynol) | | |
| Fabrics and Nonwovens | | |
| Modified Nomex (Durette) | Abrasion Resistance | Outer Shell, Inner Shell, Gauntlet and/or Palm Fabrics, MLI Spacers |
| Aramid (Kevlar 49 and 29) | Flammability | |
| Nomex (Woven, Knits, Nonwoven and Papers) | Strength | |
| Polyester (Nonwoven) | Thermal Conductivity | |
| Fiberglass (Scrims) | | |
| Metallic (KARMA) | | |
| Hybrids (Orthofabric) | | |
| Coatings | | |
| Silicone | Flammability | Coatings for Outer Palm, Inner Shell, Thread Hole Sealant, etc. |
| Urethane | | |
| Fluorel | | |
| Neoprene | | |

TABLE 3-2. SUMMARY OF THERMAL INSULATION CONCEPTS

| Approach | Material Types |
|---|---|
| Low Conductance Materials | Multilayer Insulation<br>Foams<br>Powders<br>Felts |
| Thermal Standoff Materials | Honeycomb<br>Fibertran*<br>Velcro** |

* Trademark 3M
**Trademark, The Velcro Corporation

Powders

The use of powders to obtain the required thermal insulation was also evaluated. While some concepts such as fine glass beads would have advantages such as lack of flammability, the potential for contaminating adjacent systems should leakage occur and the difficulty in working with powders resulted in eliminating them from consideration.

Felts

Examination of both felt and batting conductance data showed considerable promise as a candidate insulator. Felts maintain considerable thermal integrity under compressive loads. They also transfer both shear and normal forces, and they are easy to work with. Unfortunately, they are relatively stiff which would impact glove mobility. Finally, only a limited amount of data were available as to compressibility effects (i.e., changes in conductance with compressive load). An earlier section mentioned literature and industry survey had provided a basic knowledge of what materials were available and samples of a number of the felt candidates. Analyses indicated that overall advantages could be achieved if two densities of felt were used in two areas. A relatively low density felt could be used in the gauntlet area, while the finger and palm regions required a relatively high density felt both for thermal protection and transfer of tactile information. Accordingly, a test program was implemented to develop the required data. Materials included in this program are summarized in Table 3-3.

Felts selected for testing used materials which were suitable for NASA's EVA thermal glove and which were known to be readily available. Table 3-3 summarizes the felts tested. PBI was not included due to uncertainty as to availability. Insufficient Polymide felt was available for testing. The weights listed in Table 3-3 were determined on small samples and are considered approximate.

TABLE 3-3. FELT TEST MATERIAL SUMMARY

| Material Type | Style | Symbol[1] | Initial[2] Thickness (Inch) | Weight[3] (oz/$ft^2$) | Density (lb/$ft^3$) |
|---|---|---|---|---|---|
| Durette (400-11)[5] | NASA SLB 13100197 | ⊙ ⊡ | 0.128 | 0.92 | 5.39 |
| Kevlar | NASA Sample | | 0.066 | 0.82 | 9.32 |
| Teflon | GAF TE-2050 | | 0.060 | 2.10 | 26.25 |
| Nomex | NASA (Globe-Albany[4] S/18 72 NR) | | 0.070 | 1.93 | 20.68 |
| Nomex | GAF, No. 114 | | 0.079 | 1.57 | 14.91 |
| Nomex | GAF, 62HT8 | | 0.280 | 0.81 | 2.17 |

Note:

1 Symbols as used in Figure 3-1.

2 At 0.31 lb loading on 2 inches x 2 inches x full thickness compression samples

3 Approximate weight based on 1 inch x 1 inch x full thickness sample.

4 Scrim supported.

5 Fire resistant treated Nomex.

The loads used represented those expected to be encountered in the palm region of the glove 0-55160 N/m$^2$ (0-8 psi). Each load was maintained for 3 minutes and the amount of deflection continuously monitored for each load level increment. One 5.08cm X 5.08cm (2 inch by 2 inch) by full thickness specimen of each felt type was used for all loads. The effect of prior loading on the amount of thickness compression obtained was also evaluated on one sample and is discussed below. All tests were conducted at ambient conditions. The amount of thickness recovery after application of the maximum load used was also monitored and the value obtained at the end of 3 minutes is also reported below.

The data generated on materials listed in Table 3-4 are summarized in Figure 3-1 and 3-2. Figure 3-1 provides data for felt to be used in the palm area. Figure 3-2 provides data on the gauntlet felt. It is emphasized that Figure 3-1 only compares those specific felts listed in Table 3-3. For example, Figure 3-1 should not be interpretted to imply that Durette felts inherently compress more than do Nomex felts for a given load. Such a comparison would require use of felts with the same construction, weight, yarn denier, etc.

For all felts tested and all loads applied no significant change in compressed thickness occurred from the initial application of the load to the end of the three minute loading period.

As noted above, one specimen was used for each loading cycle. One Durette specimen was utilized to apply a 6895 N/m$^2$ (1 psi) load for 20 seconds only followed by immediate application of a 34475 N/m$^2$ (5 psi) load for 3 minutes. As indicated by the bottom curve in Figure 3-1, more deflection occurred at 3447 N/m$^2$ (5 psi) for this sample than for the Durette sample which had been previously loaded to 6895 N/m$^2$ (1 psi) and 20685 N/m$^2$ (3 psi) levels for three minute intervals. This could be a true behavior or a variation within the felt sample could be present. Insufficient data was present to draw conclusions as to cause. It is, however, significant that less deflection was not encountered for the specimen loaded directly to 34475 N/m$^2$ (5 psi). If this had occurred, it would imply that prior loading significantly degraded the felt. This was not the case. As noted in Section 3-2, a loading of 34475 N/m$^2$ (5 psi) was established as approximately the maximum load expected to be encountered. Three felt samples had the load range extended to 55160 N/m$^2$ (8 psi) to confirm that no drastic compression would occur should the 34475 N/m$^2$ (5 psi) load be exceeded.

All felt materials exhibited excellent recovery of thickness after application of maximum load. Nomex, Kevlar, and Durette all returned to more than 90 percent of their original thickness. The Teflon felt recovered approximately 86 percent of its original thickness. This data is summarized in Table 3-4.

TABLE 3-4. RECOVERY OF FELTS FROM COMPRESSION LOADING

| Material | Maximum Load (psi) | Initial Thickness (inch) | Recovered Thickness[a] (inch) | Recovery (Percent) |
|---|---|---|---|---|
| Durette 400-11[b] (NASA) | 5 | 0.128 | 0.120 | 93.7 |
| Kevlar (NASA) | 8 | 0.066 | 0.060 | 90.9 |
| Teflon (GAF TE 2050) | 8 | 0.060 | 0.052 | 86.7 |
| Nomex (NASA) | 5 | 0.070 | 0.067 | 95.7 |
| Nomex (GAF 62 H1 8) | 5 | 0.280 | 0.264 | 94.3 |

Notes:

[a]Thickness determined 3 minutes after maximum load was removed.

[b]Sample subjected to 1, 3, and 5 psi loads.

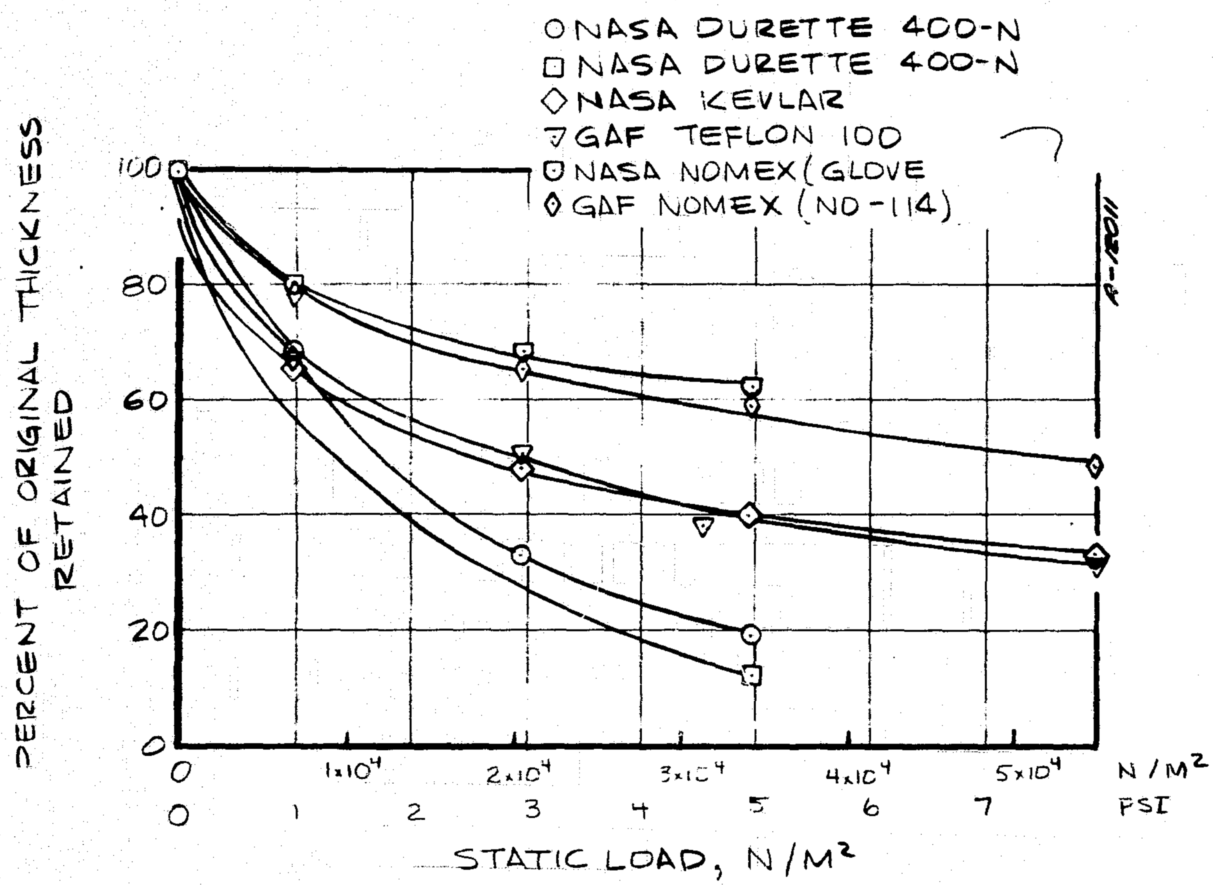


Figure 3-1. Felt compressability curves

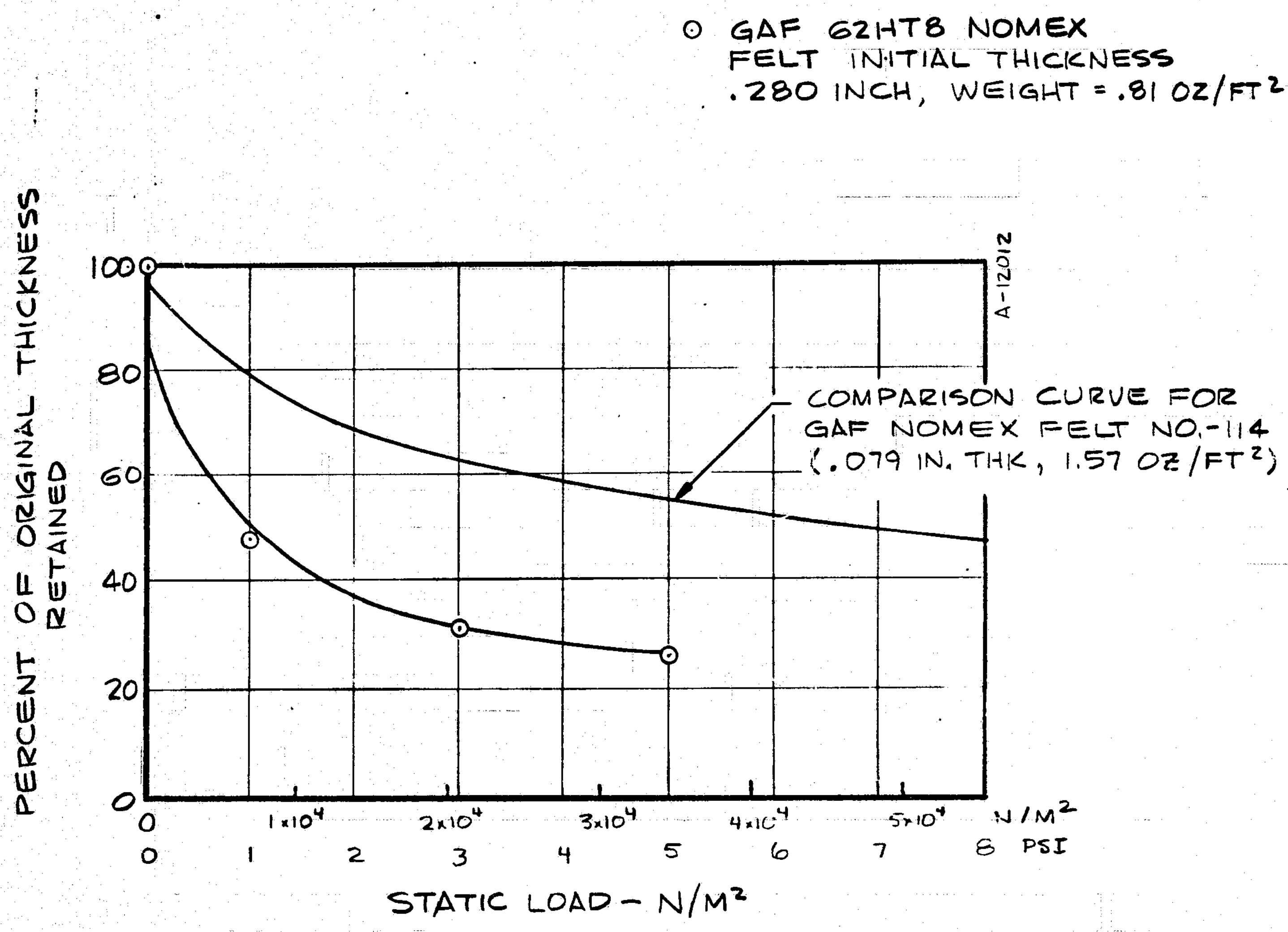


Figure 3-2. Gauntlet "fluffy" felt compression response.

The basic conclusions drawn from this work included the following:

1. The maximum compression from original thickness with pressure for all felts tested occurred within a load range of 0 to 20700 $N/m^2$ (3 psi). Above 20700 $N/m^2$ (3 psi), the compression is essentially linear within the load ranges tested.

2 From a compressibility standpoint, the optimum felts were the Glove-Albany Scrim Supported Needled Normex felt or the GAF No. 114 Nomex felt. A choice between them should be made on the basis of cost and availability. Final selection, however, should include other considerations such as thermal properties.

3. Felts recovered over 90 percent of the original thickness after compression. This characteristic is important for maintaining its insulative qualities.

Following the development of the above data and the selection of Nomex felts as described in Section 3.4, a brief investigation was made as to the dimensional stability of the felts procured. In this investigation, an approximately 3.81cm by 3.81cm (1.5 inch by 1.5 inch) by full thickness Nomex felt sample was oven exposed at 93.3°C (200°F) for 6 hours. No change in measurements were noted after this exposure.

Honeycomb

Samples of low density Nomex and fiberglass honeycomb impregnated with phenolic resins were evaluated as a thermal standoff. This approach, when used in conjunction with powders or foams, offered good insulation behavior. However, the inherent ridigity of this concept, even with slits through sections of the honeycomb, resulted in considering this approach to be questionable. Additional difficulties in incorporation of this concept into the design and fabrication led to its elimination.

Fibertran

The 3M Company markets a product under the tradename "Fibertran." This product consists of nylon 6/6 [in deniers ranging from 15 to 200 and lengths of 0.381cm (0.150 inch) and 0.4572cm (0.180 inch] fibers embedded in a semiflexible fabric backing which is coated with a solvent activated elastomer adhesive. In the form considered for this application the fibers were oriented perpendicular to the backing. The concept considered would have utilized this product either separately or in conjunction with foams to provide an insulation system providing good thermal protection and transfer of tactile information. Typical requirements established for this application included the following:

- 34500 N/m$^2$ (5 psi) load carrying capability in the fibers at 121.1°C (250°F)
- Minimum fiber area in contact with adjoining surface but high enough fiber density to eliminate radiation directly through fibers
- Sufficiently close fiber spacing to assure transmittance of tactile information
- Fibers must have low thermal conductivity
- Low emissivity backing
- Long fiber length
- Low outgassing potential/high flame resistance

Investigation of the existing Fibertran product however showed that it would be unacceptable without major modifications. Typical modifications include the use of alternate fibers, use of a backing adhesive with improved low temperature flexibility and coating with a low emissivity material. In view of the potential for systems improvements with other approaches and concepts concurrently under study as discussed in this section, the decision was made to not pursue this approach further although it potentially offered significant gains.

Velcro

The Velcro concept was also evaluated as a technique for use of the thermal standoff approach. This material system, as evidenced by the prior Astrovelcro use, offered the potential for use of an available product other than the "Fibertran" approach. The beta glass ground tape with its related hooks, backing and mating surfaces offered significant advantages. However, trial subsegment fabrication indicated that a modified "hook" without curvature would be required for maximum transfer of tactile information. Additionally, the potential for use without the mating closure could have required further modification. With the progress made in the studies conducted on felts, as discussed above, the investigation to the "Velcro" approach was discontinued.

Fire Retardant Neoprene

As discussed in Section 3.4, the use of fire retardant neoprene as a thread sealant would provide use of a well defined material. Investigation of the material received however indicated that use of the previously used cure cycle, without an accelerator, of 20 minutes at 148.9°C (300°F) would entail exposure of major glove segments to a higher than desired thermal environment. Alternately, use of the fire retardant neoprene with the trimene accelerator and its standard 3 days at room temperature cure cycle would be difficult to employ on a production

basis. Use of the fire retardant neoprene then necessitated development of an improved cure cycle. An investigation was conducted entailing use of alternate accelerator concentration, temperatures and cure times. This included fabrication of subscale glove segments and curing in both horizontal and vertical positions to check for possible runoff of the neoprene sealant. This developmental investigation resulted in the component mixture and temperature/time cycles indicated in Section 4.

Silicone Rubber Coated Kevlar Fabric

The Kevlar/Nomex fabric blend selected for use in the outer palm glove segment (see Section 3.4) was recognized as an inherently difficult material with which to achieve coating to fabric adhesion. Basis of this difficulty lay in the non-polar nature of the aramid (Kevlar) system. The initial work on preparing silicone coated fabrics entained use of a one part RTV silicone (RTV-108). The first attempts to produce an acceptable coated fabric by direct coating were unsuccessful owing to poor coating adhesivion. The coating procedure was then modified to dilute the RTV-108 with toluene to achieve a more uniform coating through the fabric thickness. This provided some improvement but ultimately proved unsuccessful in the prototype glove evaluations. The failure mode encountered was a general peeling of the silicone elastomer from the fabric coupled with low inherent abrasion resistance of the silicone.

To remedy this problem, an expanded investigation was conducted into candidate silicone systems both with and without primers. The matrix of silicone systems and primers evaluated is summarized in Table 3-5. An initial screening of the primers based upon extent of discoloration and stiffening of the Kevlar fabric (with attendant potential thermal problems) resulted in the elimination of the SS-4004 primer.

TABLE 3-5. SUMMARY OF SYSTEMS EVALUATED FOR KEVLAR FABRIC COATING

| Elastomers | Primers |
|---|---|
| RTV 108* | GE SS 4004 |
| RTV 108 + Toluene* | GE SS 4044 |
| RTV 615(1) | GE SS 4124 |
| Armoflex silicone rubber(2) | GE SS 4155 |

*For comparative purposes

(1)A 2 part dimethyl compound RTV

(2)A proprietary compound used with VM & P Napta diluent.

Additionally, variations in cleaning procedures for the Kevlar fabric were investigated. These procedures included scouring, heat cleaning, water washing, and washing in water-diluted commercial cleaners. Within these variables, the effects of different silicone compound dilution levels, varying coating thicknesses and number of silicone coats onto the cleaned and primed fabrics were considered. The effectiveness of these trials were in all cases evaluated by manual abrasion, flexing, visual observations of the silicone penetration into the fabric yarns and frictional comparisons. The evaluation samples all were constructed to duplicate the actual glove construction. This consisted of placing a segment of aluminized mylar under the fabric prior to priming and application of the silicone rubber. In all cases, after cure, the aluminized mylar was examined for degradation. As a result of this, the selected process and materials included the following:

1. Wash in diluted commercial cleaner followed by rinse and heat dry
2. Prime with SS-4155 primer
3. Coat with GE 615 silicone
4. Oven cure

After completion of the 100,000 cycle flex test with retention of coating continuity and adhesion the above cited problem was considered to be resolved.

### 3.3.2 Thermal Analysis

The thermal analysis presented herein is based in part on an inhouse computer code. In that this code, CMA/SIIT (Charring Material Ablation/Skin-Insulator Transient Thermal), is germain to the technical discussion, it will be reviewed first.

#### CMA/SITT Code

The CMA computer code was selected from Aerotherm's library of thermal analysis programs for the glove predictive problem solving task. CMA is a Fortran IV computer code which computes the transient thermal response of insulation materials. The program is for one-dimensional bodies, but can treat a variety of shapes, including planes, cylinders, spheres, and more general thermal "stream tube" bodies.

An unusual feature of the code is the very general heated surface boundary conditions, which can account for

- Simple specified temperature
- Specified heat flux

- General thermochemical ablation model incorporating complete chemical ablation computations, both equilibrium and nonequilibrium, for any material exposed to any environment.

The code has seen extensive use for thermal performance studies of ablating spacecraft structures, rocket nozzles, and heat shields. The code solution utilizes an implicit, finite-difference computational procedure for evaluating the one dimensional transient transport of thermal energy in a three-dimensional isotropic material. The program permits up to eight different materials of arbitrary thickness. The back wall of the composite material may transfer energy by convection and radiation.

The surface boundary condition may take one of three forms:

Option 1 – General convection-radiation heating with coupled mass transfer, using a transfer coefficient approach, including the effects of unequal heat and mass transfer coefficients and unequal mass diffusion coefficients.

Option 2 – Specified surface temperature and surface recession rate.

Option 3 – Specified radiation view factor and incident radiation flux, as functions of time, for a stationary surface.

Any combination of options may be used for a single computation. Option 3 is appropriate to cooldown after termination of convective heat input and is often useful in conjunction with Options 1 and 2.

This code was originally conceived for the analysis of the thermal response of multiple layers of insulators undergoing heating during atmospheric reentry. As a consequence, the program incorporates several capabilities that are specific to reentry vehicle design and that were not employed in the thermal glove analysis. The code, when operated with the thermal glove inputs in its abreviated format, was referred to as the SITT response code.

Given the appropriate heat flux or surface temperature boundary conditions and the necessary material thermal characteristics, the code was capable of preforming all the required transient thermal analysis of this project.

In order to use the code accurately to quantitatively predict the thermal response of any particular glove insulator layup it is necessary to extend the cross section analysed to include the uppermost skin layers of the epidermis and dermis. Additionally, the in-depth core response of the hand, below the dermal layers, was modeled with a constant heat transfer rate

TABLE 3-6. HUMAN SKIN PROPERTIES

| Tissue | Node | Thickness (μm) | Depth (μm) | Specific Heat (Cal/gm°C) | Density (gm/cm$^3$) | Thermal Conductivity (Cal/cm sec°C) $*10^{-4}$ | Absorptivity |
|---|---|---|---|---|---|---|---|
| Epidermis | 1 | 25 | 12.5 | 1.0 | 1.0 | 5.5 | 1.0 |
| | 2 | 50 | 50.0 | 1.0 | 1.0 | 6.5 | 0.0 |
| | 3* | 50 | 100.0 | 1.0 | 1.0 | 7.5 | 0.0 |
| Dermis | 4 | 100 | 157.0 | 1.0 | 1.0 | 9.0 | 0.0 |
| | 5 | 200 | 325.0 | 1.0 | 1.0 | 11.0 | 0.0 |
| | 6 | 375 | 612.5 | 1.0 | 1.0 | 12.5 | 0.0 |
| | 7 | 500 | 1050.0 | 1.0 | 1.0 | 13.5 | 0.0 |
| | 8 | 650 | 1625.0 | 1.0 | 1.0 | 13.8 | 0.0 |
| | 9* | 100 | 2000.0 | 1.0 | 1.0 | 14.0 | 0.0 |
| Adapoise | 10 | 2000 | 3050.0 | 0.5 | 1.0 | 4.0 | 0.0 |

*Note: Nodes 3 and 9 are split halfway between the epidermis and dermis, and the dermis and fat tissue respectively.

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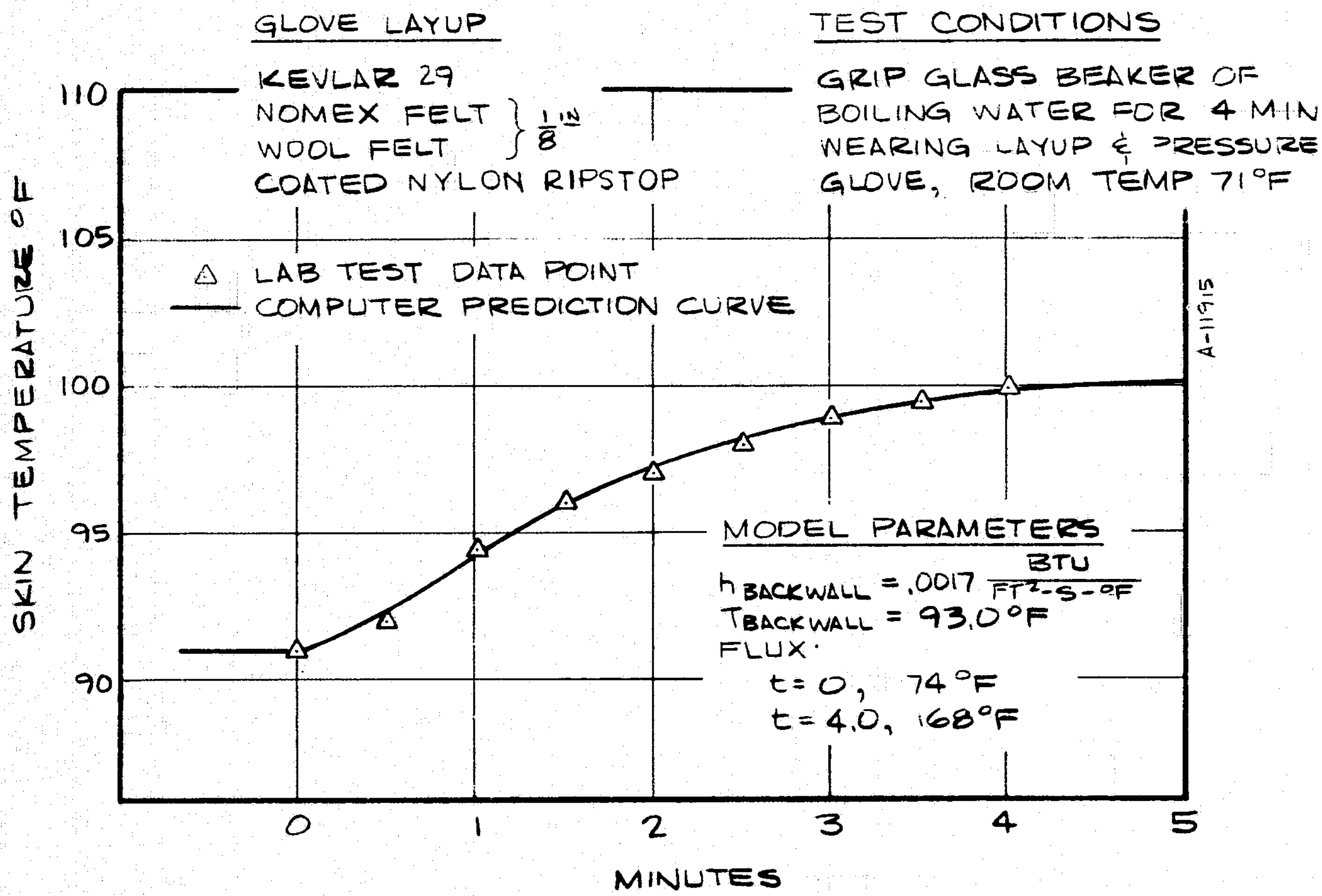



Figure 3-3. Comparison of SITT code model prediction with laboratory test data.

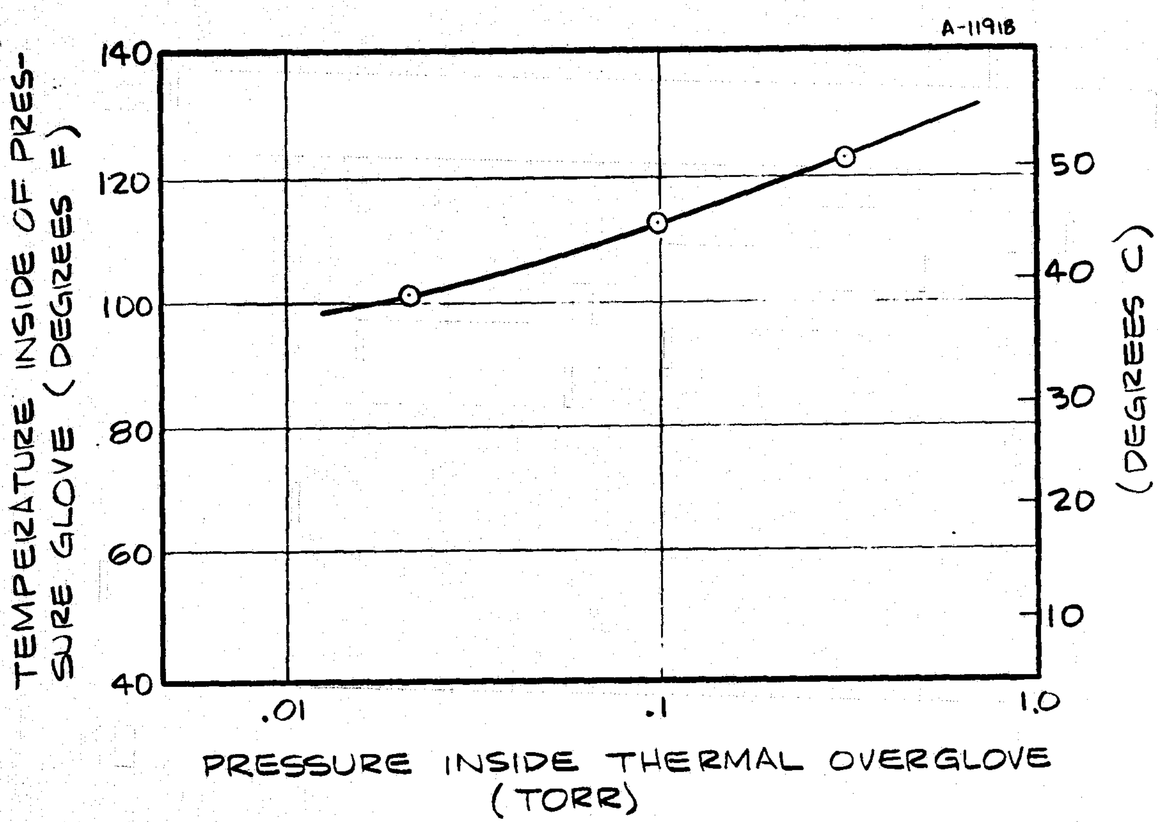



Figure 3-4. Skin surface temperature after contact with 93.3°C (200°F) bar for 3 minutes as a function of GFE's thermal overglove internal gaseous pressure level.

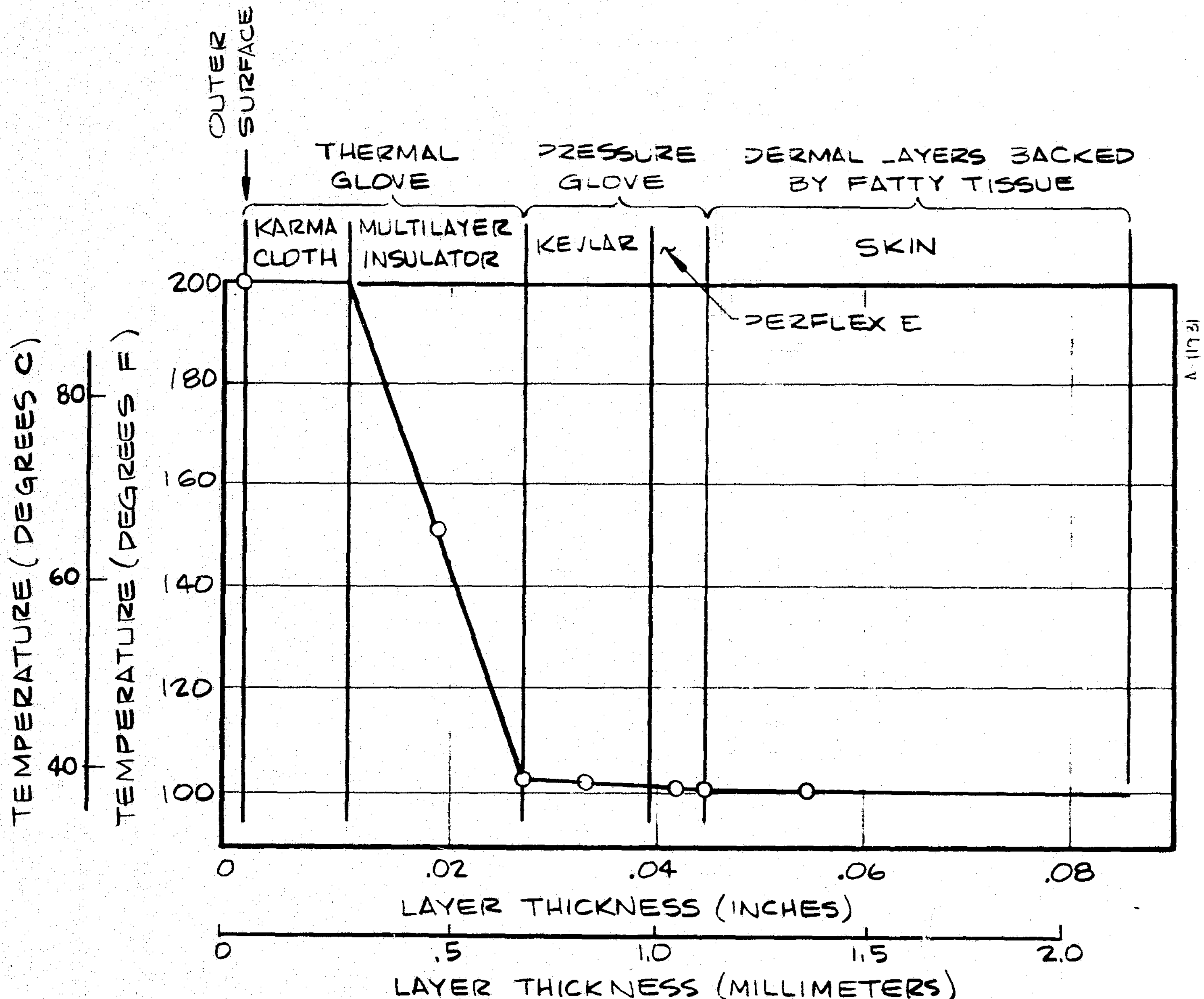



Figure 3-5. Temperature distribution through GFE pressure glove and thermal glove configuration after 3 minute contact with a 93.3°C (200°F) surface.

## Objective of Thermal Analysis

The thermal analysis task had two primary objectives. The first was to aid in the selection of the basic type of insulator and the second was to anlayze the performance of the selected insulator in various layups and under different design conditions.

To satisfy the first requirement, three different insulators had to be examined in some detail before a recommendation could be made. The candidate primary insulator materials considered were a fibrous standoff type, a conventional multilayer radiation shield layup and a Nomex felt.

## Fibrous Standoff Analysis

The analysis of the fibrous insulator required the itterative use of the SITT program to model the dual heat transfer mechanisms of conduction along the parallel fibers and radiation between the gaps in fiber array. The situation analyzed is pictured in Figure 3-6a.

Because input of both a surface temperature and a radiant flux was not provided for in SITT the problem was solved as follows. A surface temperature was input and the conduction only through the fiber standoffs used to determine the temperature at the base of the fibers. This temperature and the outer surface layer temperature of 93.3°C (200°F) were then used to calculate the radiation transfer across the open volume and this was added to the conduction flux. This total was then input to the program and a new temperature response calculated. The procedure was repeated until the temperature at the base of the fibers no longer increased; that is, until the effect of both the conductive and radiative transfers was reflected in the temperature response of the surface being irradiated.

The result of this analysis was the determination that the fibrous insulation alone, of a thickness practical to consider placing on a tactile area, was adequate to insulate against conductance but, when radiation was added to the solution, allowed skin surface temperature to reach nearly 58°C (136°F) at the end of 3 minutes of contact with the 93.3°C (200°F) surface.

Accordingly, a second configuration was analyzed and is pictured in Figure 3-6b. This was identical to the first standoff except for the addition of a layer of foam approximately half the thickness of the fibers and located around their bases. The intent was to provide a layer of insulator that would not degrade the operation of the standoff insulator, but at the same time would alleviate the problem of high radiant transfer between the outer

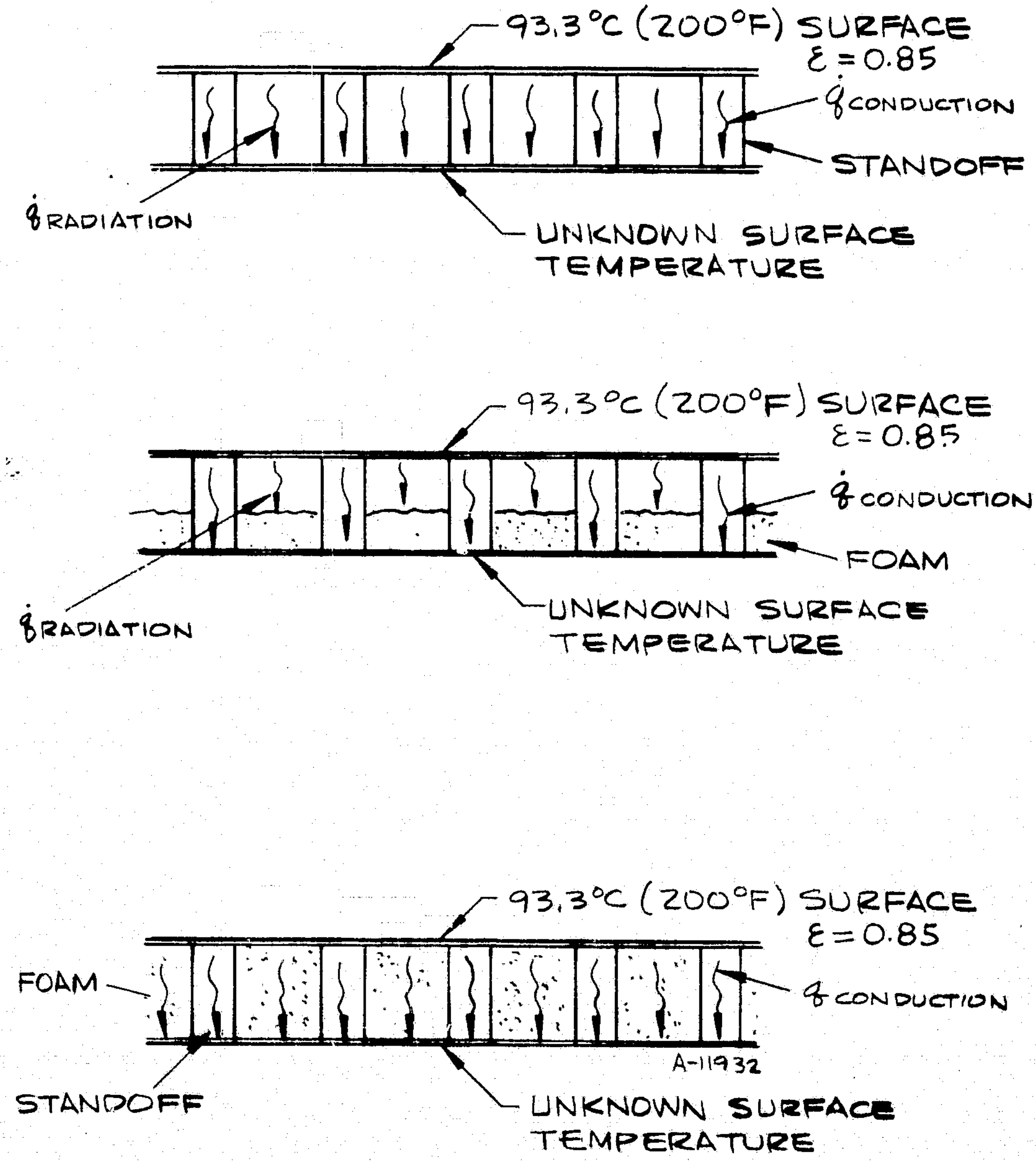



Figure 3-6. Cross-sections of standoff insulators analysed by SITT code.

fabric layer and the base layer for the standoff. Thus the low contact area and long conduction path length of the standoff was preserved and additionally, a radiation shield was provided.

The result of the analysis for this layup was the conclusion that it performed adequately for protection against 93.3°C (200°F) surface contact for periods longer than 3 minutes with the skin temperature being 41.7°C (107°F) at the end of that period.

Consideration was finally given to the case where the foam layer was in contact with the outer fabric layer (Figure 3-6c) as might occur with the bending of the standoff under high grip forces or due to production foaming variabilities. This did not involve any internal radiation transfer and a composite conductance based on surface area of the foam and the standoff fiber tips was used for the insulator. The results of the 93.3°C (200°F) contact case were very poor with the 43.3°C (110°F) skin temperature condition being exceeded within 30 seconds. The layer of foam was inadequate to insulate the hand and the fibers only served to degrade the foam's insulation properties.

Primarily because of this drastic change in the insulating quality of the standoff/foam layup should the standoff collapse, along with subsequent problems in production of even the standoff without the foam, this candidate dropped from consideration for use on the thermal glove.

The two remaining candidate primary insulators for the glove were the felts and multilayer insulators (MLI). The rationale for the final selection are discussed below.

Selection of Felt over MLI

Felt was selected over MLI as the primary thermal insulator in the thermal overglove in the tactile areas and in the gauntlet. The tradeoff studies that lead to this decision are discussed below.

Thermal Analysis of Felts and MLI

The most important thermal property for the felt to be used in the finger and palmar areas is the effective thermal conductivity and its minimum degradation under a compressive load. From the standpoint of thermal design the chosen felt should exhibit the following nominal characteristics. At reduced pressures (less than $10^{-3}$ torr), the effective thermal conductivity should be no greater than 15.6 Joules/meter-sec-°K (0.03 Btu-in/ft.sq.-hr-°F) in the medium and low temperature range (37.8°F) and no greater than 46.7 Joules/meter-sec-°K

(0.09 Btu-in/ft.sq.-hr-°F) at higher temperatures. These values were selected based on parametric studies using the Aerotherm SITT code and experimental properties of felt. Plots of these data are presented in Figure 3-7. In the final analysis, the objective is to select a felt, and its thickness, which will protect the hand within the design specification for the cold or hot bar test, incident solar radiation case, and radiation to cold space. Additionally, the heat flux through an insulator should not be increased by more than a factor of three when a 34500 N/m$^2$ (5 psi) compression load is applied to the hand.

The ability of the felt to meet this last condition is largely a function of its density and fiber stiffness. The basic thermal conductivity requirement can be met by Nomex felts in the 112 to 128 Kg/m$^3$ (7 PCF to 8 PCF) density range (see Figure 3-8). Further, a limited amount of compressibility data on a comparable 128 N/m$^3$ (8 PCF) Nomex felt was available for the analysis (Reference 5).

The coefficient of thermal conductivity does not present the best means of comparing felts to MLI because this factor does not reflect the actual thicknesses involved. It is suggested that comparisons be made by examining the effective conductance, which is a measure of the heat flux passing through a specific layup cross-section per °C (°F) of temperature difference across that layup. Such a plot is presented in Figure 3-9 for 128 Kg/m$^3$ (8 PCF) density Nomex felts of two different thicknesses 0.318cm (1/8 inch) and 0.634cm (1/4 inch) where the conductance varies with compressive loads. Additionally, a data point for the actual 128 N/m$^3$ (8 PCF) felt layup used on glove IA is plotted.

This graph is a convenient format for comparing felts and MLI. Conductance data for 7 layers and 3 layers of MLI layups are presented too. The 7-layer MLI data were taken from Reference 6 while the 3-layer MLI data were obtained by simply scaling the 7-layer data to account for the decreased thickness of the layup.

These data are most informative because it indicates that, owing to the difference in the slops, cross-overs exist between the two types of insulation in terms of compressive load. In general, we note that for pressure loads of 34500 N/m$^2$ (psi) and above, both 7-layer MLI layups and 0.38cm (1/8-inch) felt thicknesses provide comparable conductances and hence, comparable protection. This observation is particularly true if you extend a line through the data point for the actual grip surface layup parallel to the Hitco felt curves. In which case the extrapolated performance of the Phase IA glove layup at 34500 N/m$^2$ (5 psi) load is superior to a 7-layer MLI layup by almost a factor of 2 and to the 3-layer MLI layers

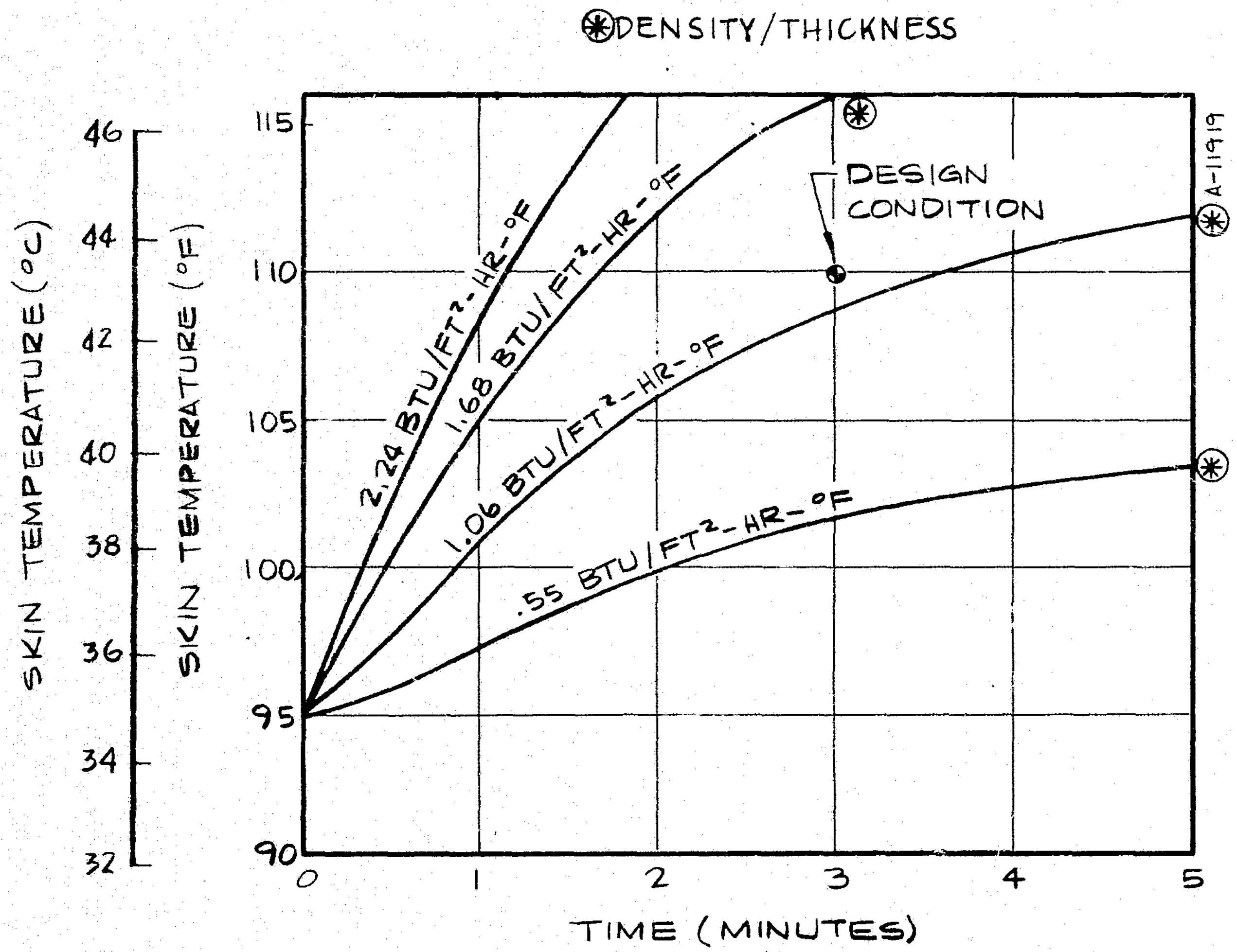



Figure 3-7. Skin temperature response for various conductance layups in contact with 93.3°C (200°F) bar.

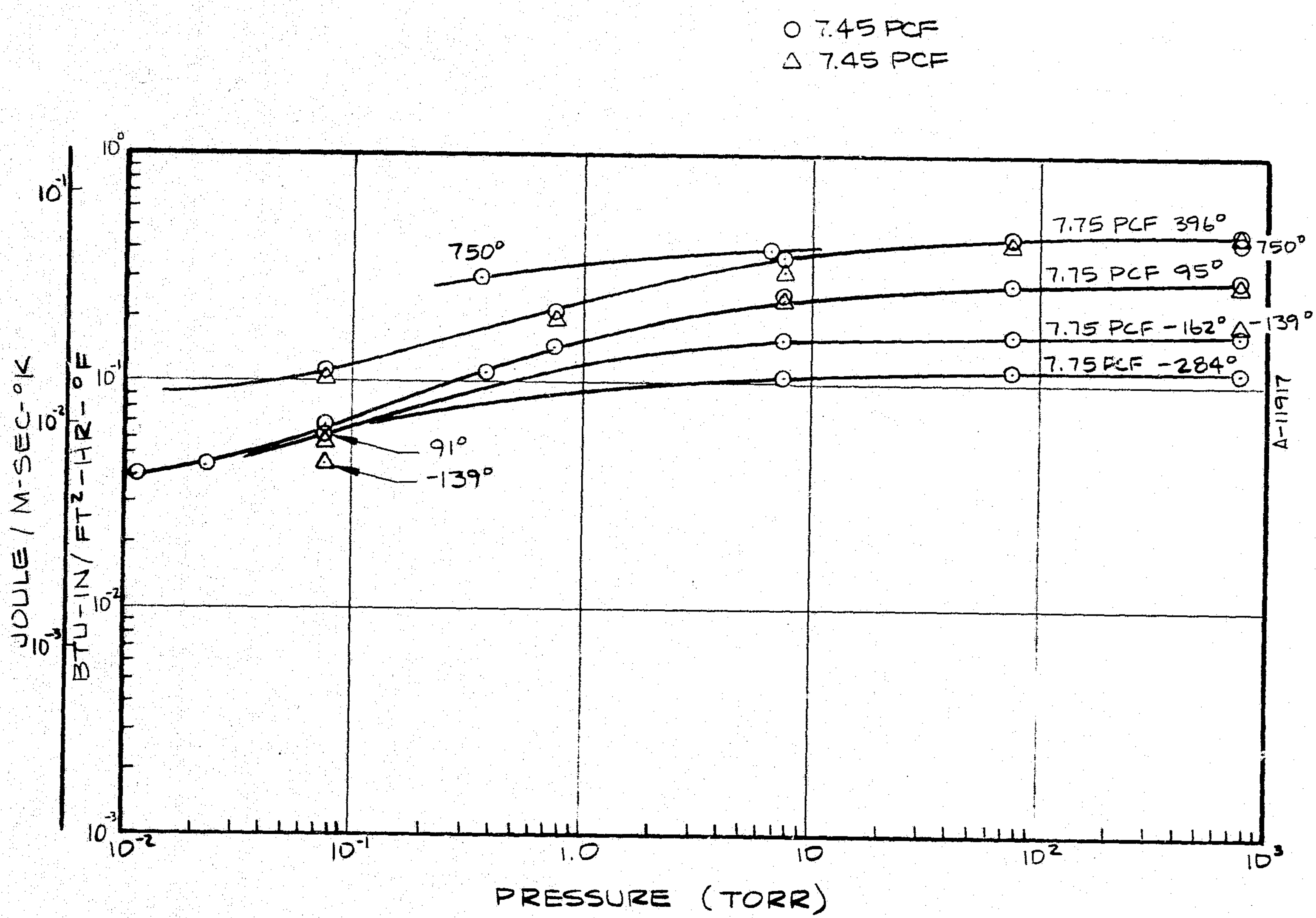



Figure 3-8. Nomex felt thermal conductivity without loading.

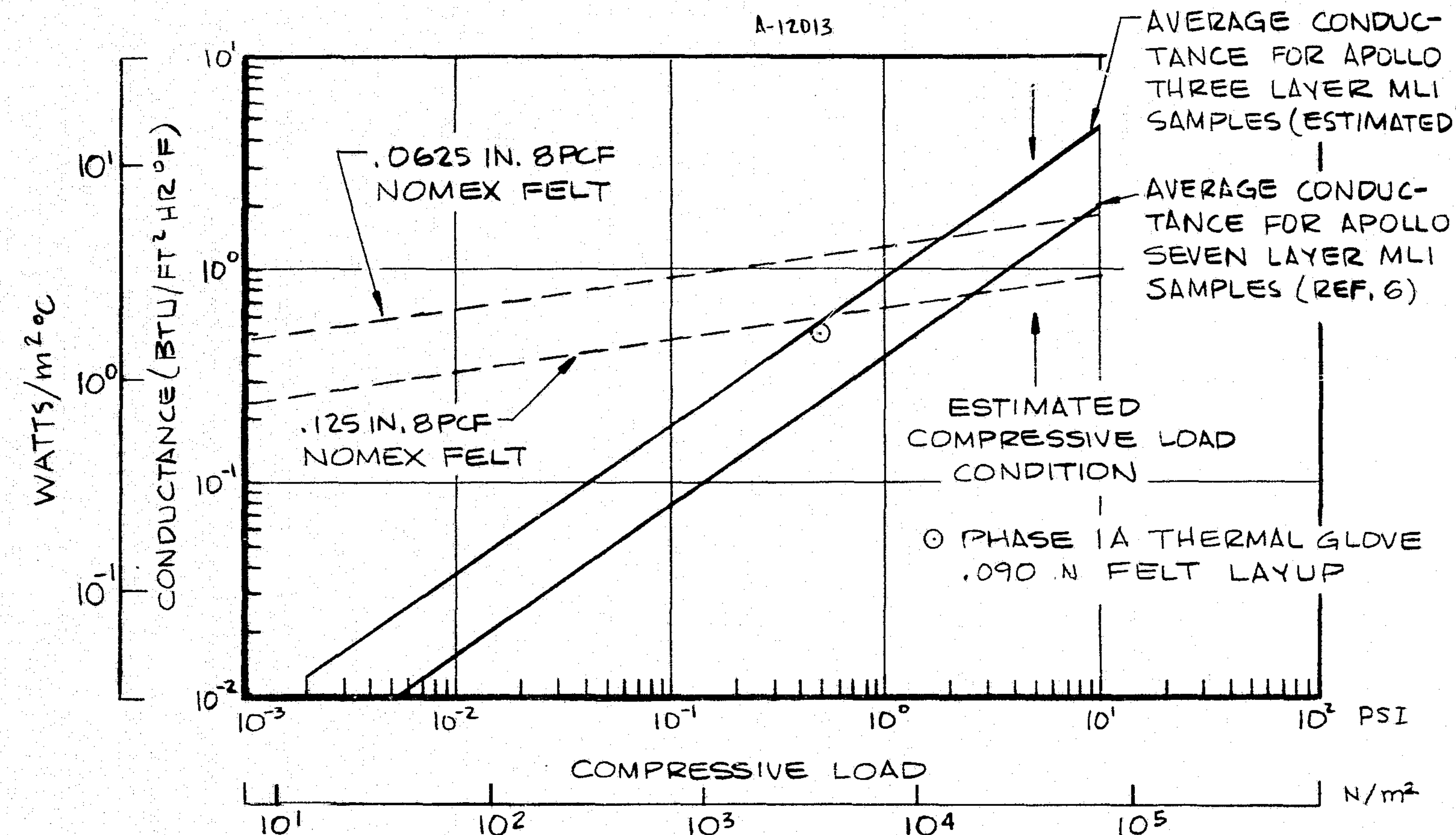



Figure 3-9. Effect of compressive loads on candicate insulator conductance.*

*Insulator temperature 100-200°F. Internal pressure less than $10^{-3}$ torr.

by more than a factor of 3. Equivalence of the Phase IA with the 7-layer layup occurs at 12400 N/m$^2$ (0.3 psi) and with the 3-layer layup.

Thermal Response of Grip Surfaces

The grip surfaces of the palm and finger anterior were analyzed under two conditions 93°C and -129°C (±200°F) surface contact and direct solar radiation. The cross-section considered is given in Figure 3-10 and the computer inputs for the various layers is listed in Table 3-7. For the case of the hot bar contact the computer was simulation run for 5 minutes and the resultant temperature history of the epidermis is given in Figure 3-11. The thermal conductivity programmed for the felt was that for the material under a 5 psi compressive load and was derived by reducing the effectiveness of the uncompressed felt by a factor of 3 and programmed as a function of internal insulator temperature. This adjustment is based on the experimentally derived compressability data discussed in Section 3.3.1.

For comparison, the response of the 7-layer MLI insulator to the same load and surface temperature is shown in Figure 3-11 Both the layups provided adequate protection with the felt being a slightly superior insulator. This is due to the assumption here of a 34500 N/m$^2$ (5 psi) loading condition which seriously degrades the MLI insualtor (see Figure 3-12). As the load on the insulators is decreased, the MLI would become the more effective of the two.

This is seen to be the case in Figure 3-13 which is the temperature response of the skin under the two different insulators when exposed to a normally oriented solar flux of 144 watt/m$^2$ (0.127 Btu/ft$^2$-sec) as received in earth orbit. In this analysis both of the insulators are unloaded and perform adequately under the relatively light thermal flux of solar radiation.

As part of the analysis it was also necessary to determine the critically of seam placement and the effect of accidental seam contact with the hot surface or extended exposure to solar radiation. The two curves in Figure 3-14 show the results of these computer prediction runs. The layup analyzed is essentially that of the grip surfaces except that the felt insulator was removed and the thickness of the Kevlar fabric to represent the seam.

The desirability of designing and constructing the glove such that seams are out of possible contact with the 93.3°C (200°F) surface is easily apparent. Likewise, the advisability of locating the seams where they are not in direct sunlight, oriented 90° to the fabric surface, is evident.

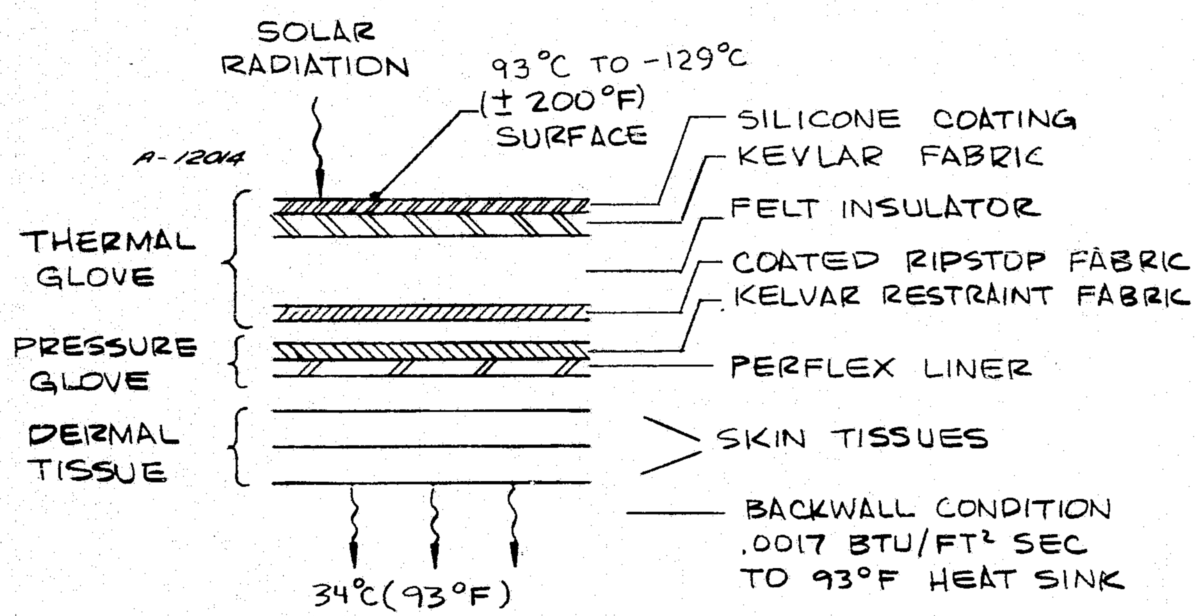



Figure 3-10. Schematic showing glove and skin laminates considered in SITT code analysis.

TABLE 3-7. SITT PARAMETERS FOR GRIP SURFACE LAYUP

| Material | Thickness mm | (Inches) | Thermal Conductivity Joule/m sec K° | (Btu-hr-R°) |
|---|---|---|---|---|
| Silicone | .025 | .001 | 4.89 | .113 |
| Kevlar | .254 | .010 | 1.63 | .504 |
| Felt | 2.286 | .090 | (.086 – .545) | (.086 – .545) |
| Ripstop | .102 | .004 | 21.19 | .490 |
| Kevlar | .305 | .012 | 21.79 | .504 |
| Perflex | .140 | .0055 | 4.76 | .110 |
| Skin | .508 | .020 | 15.57 | .360 |
| Skin | .508 | .020 | 15.57 | .360 |

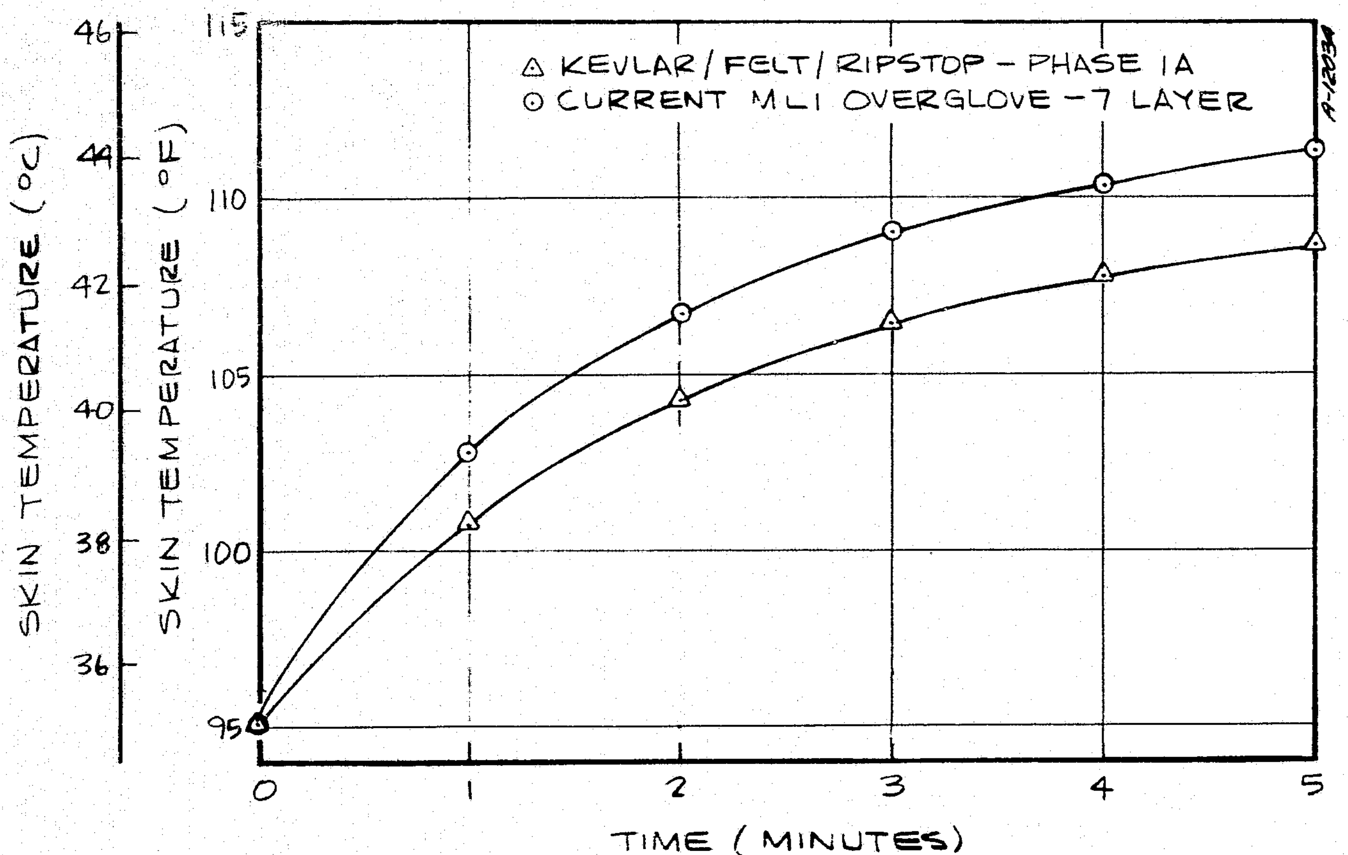



Figure 3-11. Comparison of 0.0625" Nomex felt and ILC 7-layup contacting a 200°F surface with 5 psi compressive load.

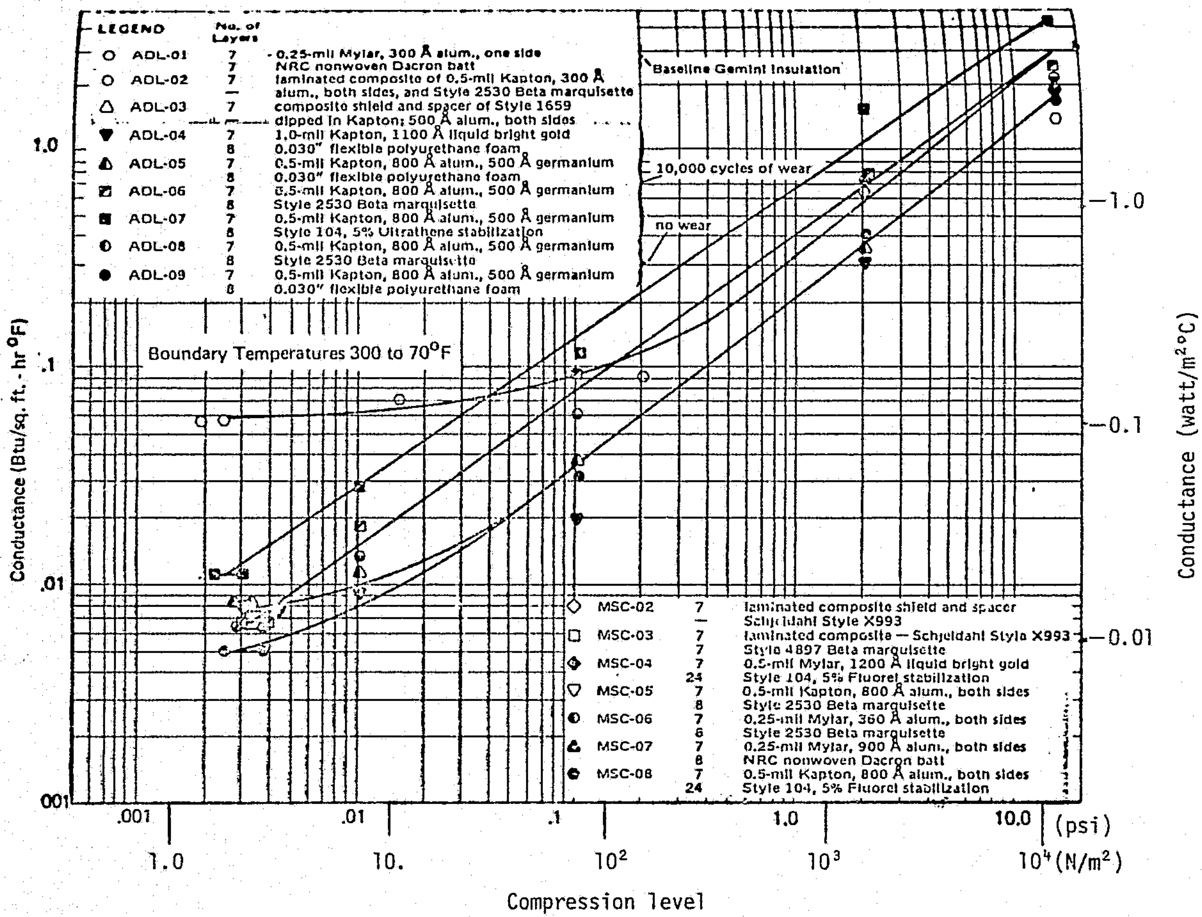



Figure 3-12a. Summary of insulation conductance — NASA/JSC samples (Reference 6).

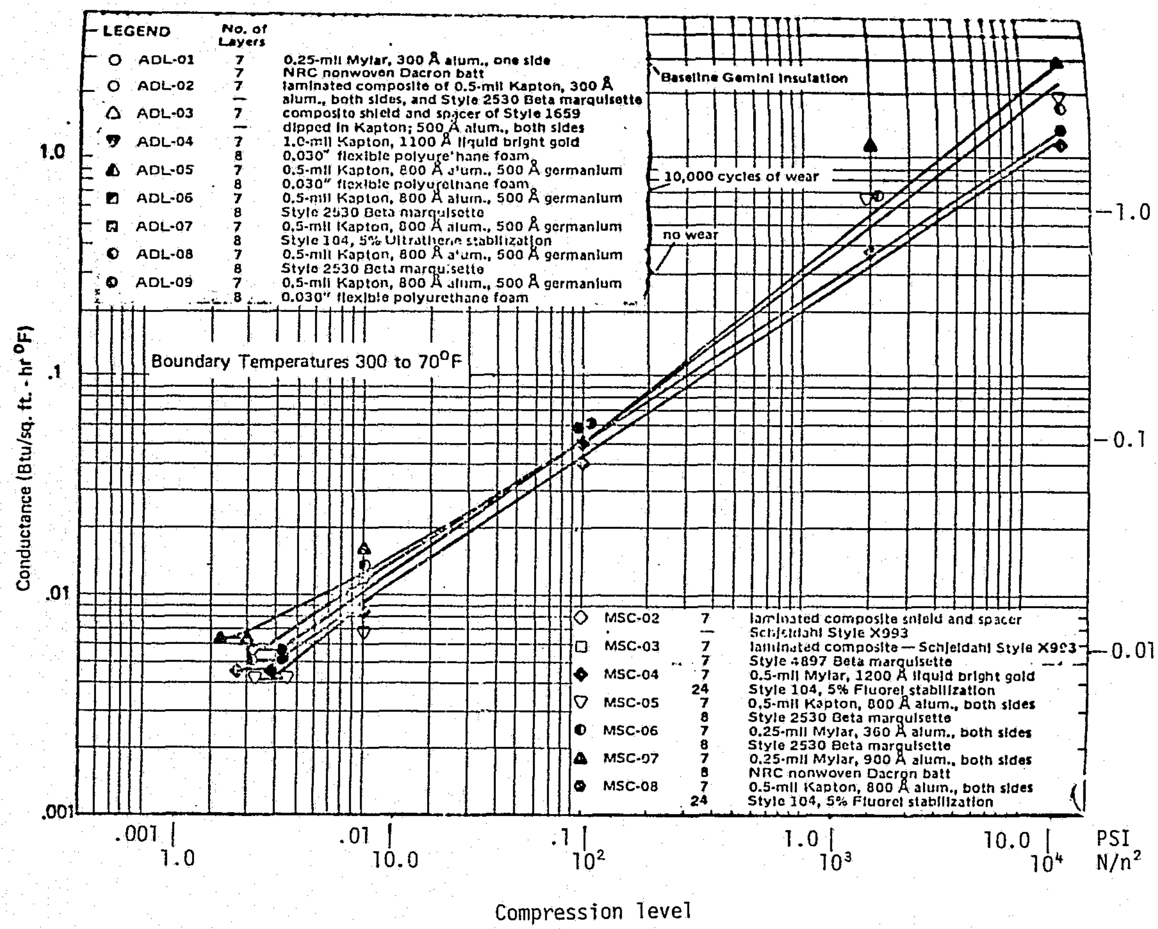



Figure 3-12b. Summary of insulation conductance — NASA/JSC samples.

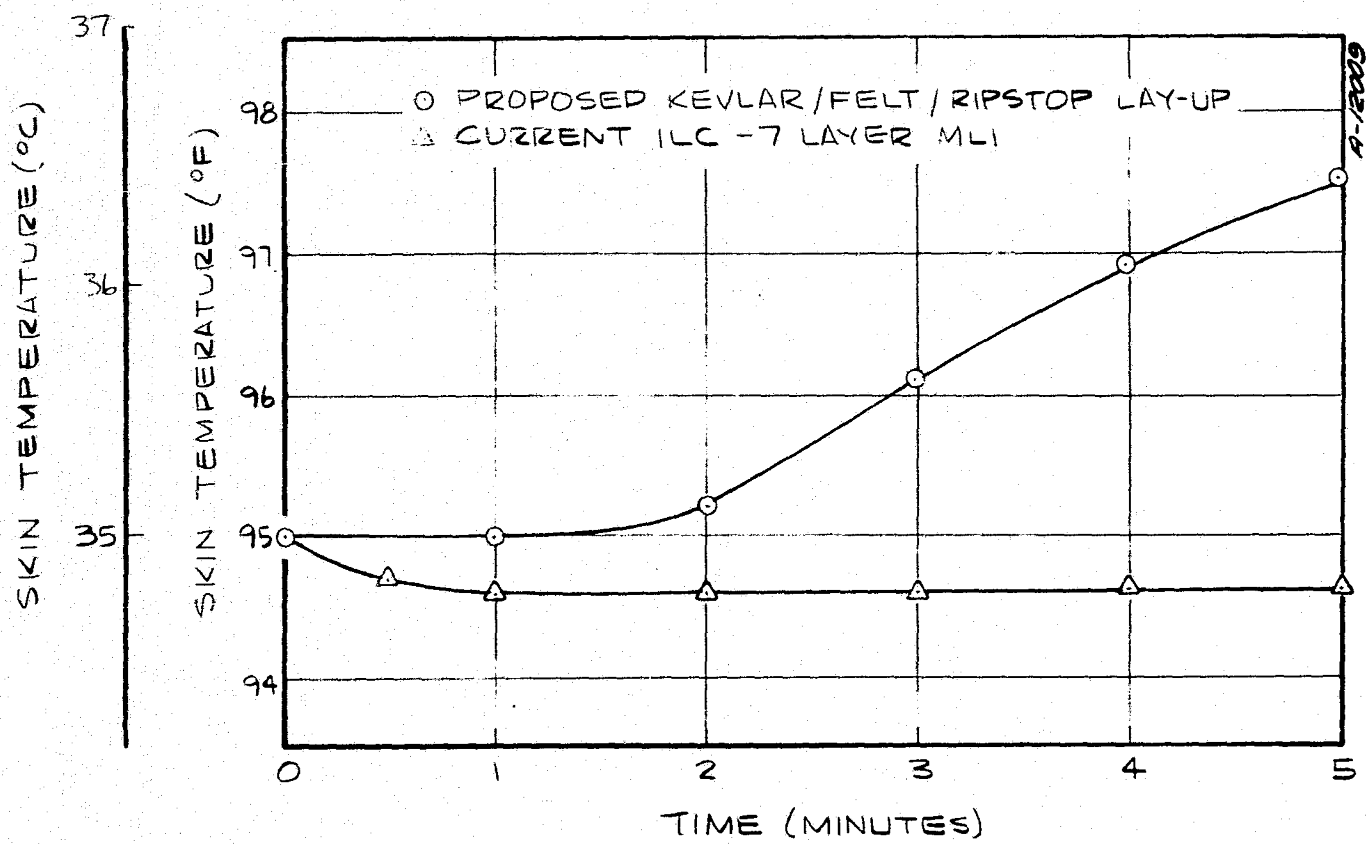



Figure 3-13. Comparison of 1.6mm (0.0625° inch) felt and ILC layup.

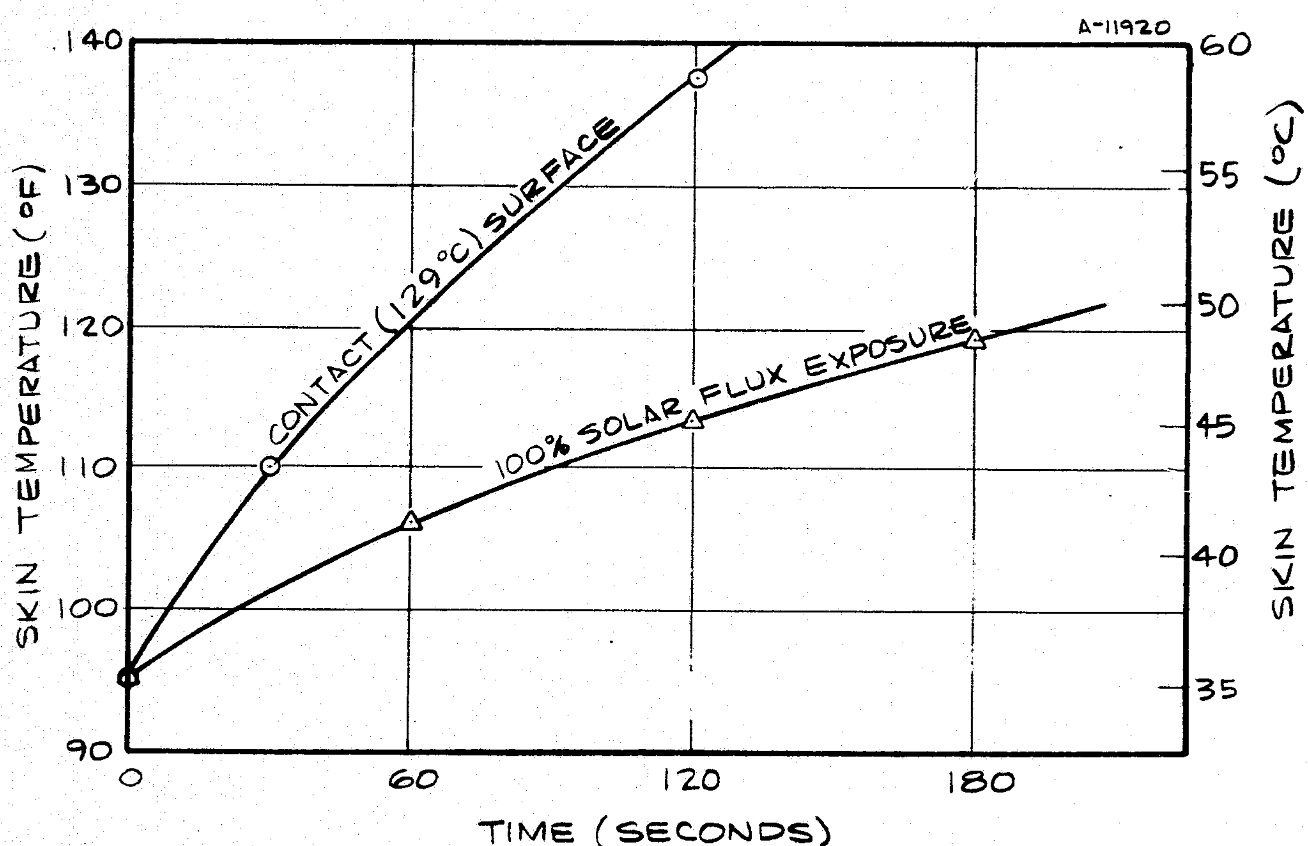
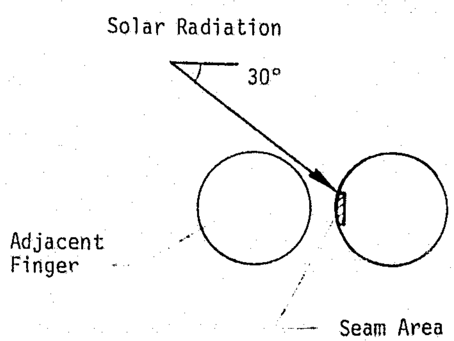



Figure 3-14. Skin temperature response under finger sidewall (seam area).

The actual design case for the finger sidewall (seam area) had the additional inputs of the seam being impinged on with solar radiation at a 30° angle and viewing the adjacent finger with a computed view factor of 0.2. This situation, diagrammed below, represents the worst physically possible solar input flux and the most likely finger geometry. In this case, the internal temperature established at a value of 34.5°C (94°F) below the 43.3°C (110°F) threshold of pain for the astronaut.




## Selection of Felt for the Palm and Fingers

Felt is preferred over MLI thermally because of its superior insulative characteristics under compressive loads as discussed in the previous section. But also, it is preferred because of its great ease in fabrication which can dramatically reduce the end item cost, equivalent material cost per unit area, and comparable tactile characteristics.

Felts can be easily handled during fabrication on a production basis. It can be treated as another fabric without great care. This is not the case with MLI which is extremely fragile and requires several layers in the final layup. Fabrication and assembly times rise rapidly with each layer because of the extra care required to handle the material and result in a more expensive product.

Tactile information is a composite of a transfer of both normal and shear forces. Both are required to define tactily an object or surface. A thin layer of MLI transfers normal forces quite well, but cannot transfer shear forces. Shear forces cause the various slick surfaces to slide over one another without transferring tactile information. Felt, on the other hand can transfer both forces. However, both normal and shear forces are attenuated somewhat in the process. It was judged tactily that felts and MLI were roughly equal, and felt was selected over MLI because of the ease of fabrication, costs, and thermal characteristics.

Selection of Felt for the Gauntlet

The choice between MLI or felt for insulating the gauntlet can be examined by looking at the three layer upper finger layup analysis and comparing it to the same analysis for a lightweight felt insulator. The worst case for the cross-section using Orthofabric for an outer layer long-duration radiation to cold space. For MLI this resulted in a 23 watt/m$^2$ (17.3 Btu/ft$^2$hr) heat loss.

Comparatively, the low density felt test data presented in Reference 7 shows a thermal conductivity at glove operating pressure which is about 10 times greater than MLI to provide equivalent protection. A three-layer MLI layup would be approximately 0.76mm (0.003 inch) to 1.0mm (0.004 inch) thick. Thus, the felt should be about 7.6mm (0.03 inch) to 10.0mm (0.04 inch) thick. This would result in the same temperature response and heat flux loss as seen before.

From a practical standpoint the thickness of felt used should not be so thin as to be optically transparent. Hence, although the analysis indicated a 0.8mm (0.0031 inch) thickness felt, would be adequate, 1.6mm (0.062 inch) should be used. Considering the 23 watt/m$^2$ (17.3 Btu/ft$^2$) heat flux rate predicted, a 1.6mm (0.062 inch) felt of low density was more suitable under the Orthofabric outer layer of the gauntlet to provide increased thermal protection.

Because felt is easier to use in fabrication and satisfies the safety requirements, low density Nomex felt was recommended for use in the gauntlet.

Determination of the Number of Layers of MLI

The dorsal aspect of the fingers required thermal insulation from solar radiation and radiation to cold space. This protection will be provided with MLI. In this case, the increased need for flexibility and the fact that this area of the glove does not require insulation while under compressive loads leads to the selection of MLI as the insulation material. The problem to be solved was to determine the number of layers of MLI to protect the hand.

From the thermal standpoint, the adequacy of three layers of MLI was examined for two cases; a normally incident maximum solar radiant flux of 1430 watts/m$^2$ (0.127 Btu/ft$^2$sec); and a long duration passively radiating situation.

The surface equilibrium temperature under solar flux was calculated in a straightforward manner using the assumed surface properties of Orthofabric ($\epsilon$ = 0.85, $\alpha$ = 0.22) and an

adiabatic backwall condition. This indicated that the Orthofabric could be expected to reach temperature in the neighborhood of 10°C (50°F) and thus no insulation would be required to maintain an acceptable interior temperature. A steady state heat flux calculation shows that the heat loss to the environment through the three-layer cross section would be less than 3 watts/m$^2$ (1 Btu/ft$^2$hr), well within the 47 watts/m$^2$ (15 Btu/ft$^2$hr) design constraint. The case of radiation to cold space then becomes the design condition for the MLI evaluation.

The use of a simplistic, steady state analysis for the cold case was not appropriate, primarily because the equilibrium surface temperature, assuming an adiabatic backwall, would be 0°K. This differs radically from the initial condition of the glove and thus transient performance is of primary interest.

Accordingly, the SITT code was used with the following inputs to model the skin and external surface temperature response: Orthofabric $\varepsilon$ = 0.85, insulation thickness = 0.076mm (0.0003 inch), 3 layers of MLI and scrim, 35.0°C (95°F) initial condition of layup and 34.0°C (93°F) backwall temperature with backwall transfer coefficient of 10.7 watt/m$^2$°K (0.0017 Btu/ft$^2$sec°R). This backwall transfer was determined earlier from laboratory tests. The layup was allowed to radiate to 0°K space with a view factor of 1.0 for 3000 seconds (50 minutes or half of a typical orbital period for shuttle). The resultant skin temperatures did not drop below 90°F although the outside glove temperature fell to below -95.5°C (-140°F) (see Figure 3-15). Thus, the MLI was quite adequate. The heat flux loss over the 50-minute period was 2.36X10$^6$ Joules/m$^2$ (14.4 Btu/ft$^2$) or about 54.5 watts/m$^2$ (17.3 Btu/ft$^2$hr) which is a marginally tolerable value and the reason for not further reducing the insulation thickness.

Consideration was also given to the passively radiating case of the side of the finger where only one layer of MLI is present. Here account was taken of radiant exchange between adjacent fingers as well as the transient situation. The surface temperature of the adjacent emitting finger was taken as previously determined in the finger dorsal aspect radiation case and a view factor of 0.2 was calculated from the appropriate geometry of parallel cylinders with known spacing. The skin temperature stabilized at a temperature slightly below 90°F.

The total heat flux lost during this period was 2.2X10$^6$ Joules/m$^2$ (20 Btu/ft$^2$) 75.5 watts/m$^2$ (24 Btu/ft$^2$hr). Considering the limited area of the sidewalls when compared to the total glove area, this, although locally in excess of the design heat loss rate, did not pose any problems for the entire glove meeting the 47.4 watts/m$^2$ (15 Btu/ft$^2$hr) loss rate as a total system.

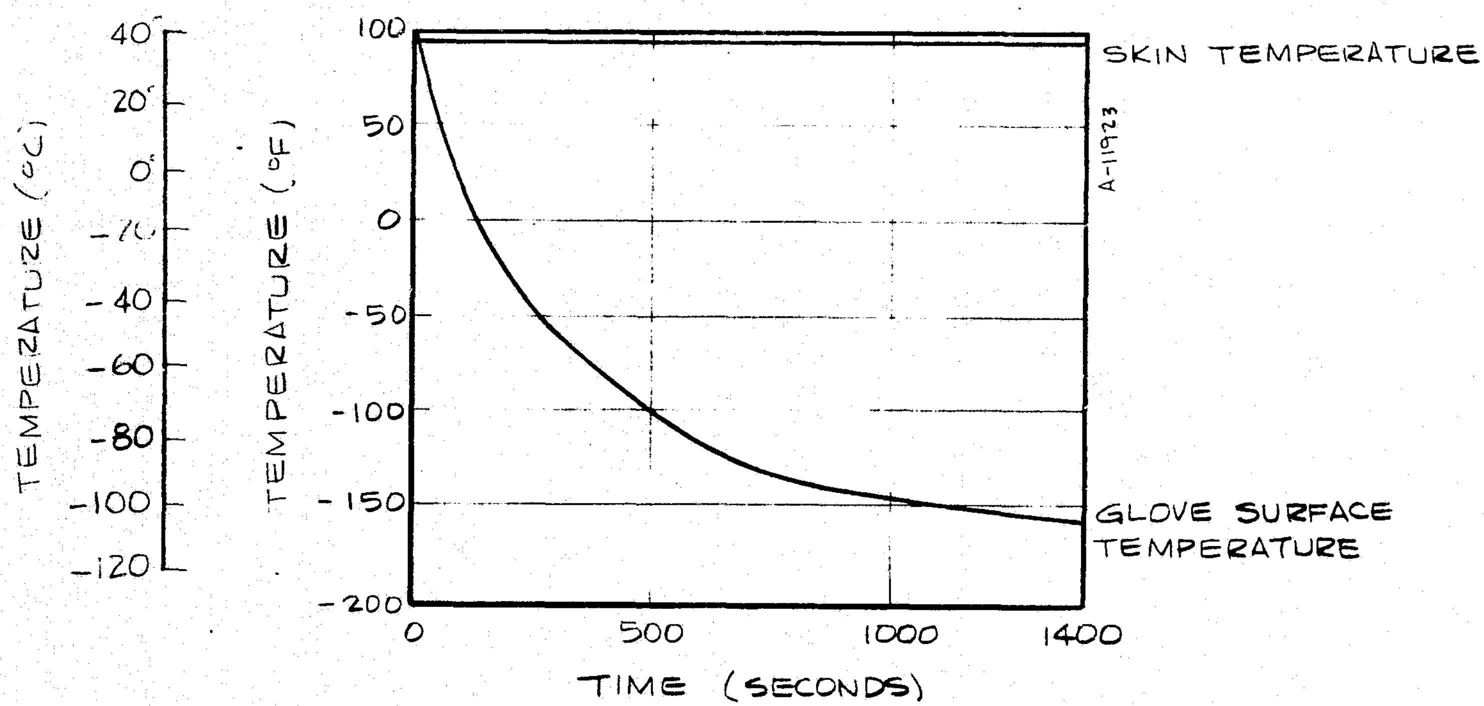



Figure 3-15. Temperature history of skin under glove surface of passively radiating Orthofabric and three layer MLI.

The outside temperature range is important for two reasons: First, it means a minimal amount of insulation is necessary under the sidewalls where bulk between fingers is critical; and second, it provides a moderate temperature zone for the ends of the MLI to be terminated. This observation is significant because the primary cause for concern over the effectiveness of MLI is its degradation due to edge effects; that is, the penetration of high or low temperatures to the inner layers at end seams, followed by lateral conduction along the shield/substrate layer.

Radiation to or from the hot or cold bar when "seen" by the sidewall represents a less severe case when compared to the solar flux and passive radiation situations and so long as direct bar contact is avoided no problems are anticipated.

Evalution of Aluminized Mylar as a Radiation Barrier

In order to examine the effects of aluminized mylar as a barrier to radiation from the high emissivity Orthofabric into the felt insulator, tests were performed in the laboratory using a specially configured mockup overglove. Two of the fingers incorporated layups which were identical except for the use of aluminized mylar in one of them. The mylar was placed between the outer fabric and the felt. The test was performed using a flask of hot water approximately 87.9°C (180°C) as the heat source and contact pressures estimated to be representative of a 34500 N/m² (5 psi) compressive load. A thermocouple output was used to measure the skin surface temperatures at 15 second intervals. The plots of skin temperature histories are presented in Figure 3-16. Three tests were run sequentially with a different finger instrumented in each test. Final temperatures and initial temperatures varyed slightly, as shown in Figure 3-16. It was observed that the test with aluminized mylar yielded approximately 1°C (2°F) improvement over the identical layup without mylar.

Variations between test runs of the simulated bar temperature and initial glove temperature must be accounted for before and definitive conclusions can be drawn. For the initial temperature adjustment, computer runs have established that a 2:1 relationship exists after 3 minutes. That is, 1°C (2°F) higher initial temperature is reflected by 0.5°C (1°F) higher final temperature. When this fact is taken into account, the final skin temperature for test No. 3 (middle finger instrumented) should be increased from 44.4°C (112°F) to 44.7°C (112.5°F) (Note Run 2 and 3 are nearly identical). Corrections for the flask temperature were not made. However it is suspected that if flask temperatures were as high for the tests without mylar as for the mylar test, the difference in final skin temperatures would even be greater, perhaps by 1.5°C (3°F).

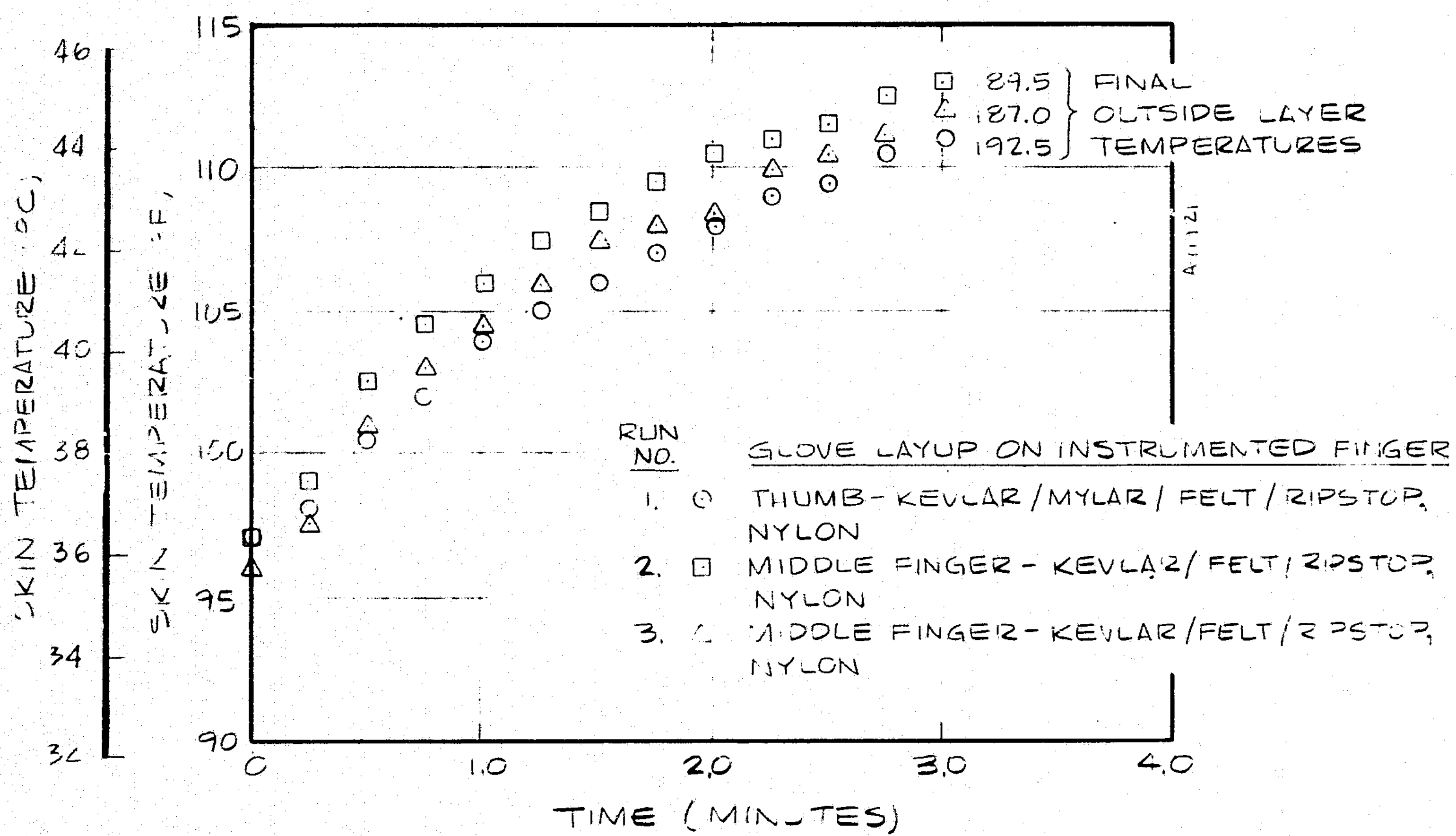



Figure 3-16. Laboratory grip test skin temperature histories for insulation layups with and without aluminized mylar.

The net effect of the mylar then was to inhibit the heat flux entering the glove. It is desirable to include one layer of aluminized mylar placed between the outer fabric and the felt, because this layer serves as a radiation barrier and improves the performance of the thermal insulation. However, this layer can be eliminated with only a small loss in protection resulting in beneficial gains in fabrication time and cost savings.

Evaluation of the Effective Thermal Conductivity of Felts at Low Pressures

In order to evaluate the thermal protective ability of various felts under compressive load and ambient pressures, data are required. An increase in compression load and ambient pressure increases the effective conductance and consequently heat transfer across it. Exact knowledge of the thermal properties of various felts is imperative for proper evaluation.

Data were collected on the effective thermal conductivity of felts. The significant data received was transmitted verbally by Mr. Richardson of Arthur D. Little Corporation (Reference 7). Several years ago Mr. Richardson tested a sample of Hitco felt (a Nomex felt) for various compression loadings. Compression loadings varied from 0 to 69000 $N/m^2$ (10 psi) as shown in Figure 3-17. These data were collected for pressures of $10^{-5}$ torr and demonstrate the effects of compression on thermal conductivity. Recently, an inhouse analysis of gaseous conduction has led to techniques for converting the effective thermal conductivity at one atmosphere pressure to very low mean pressures.

Heat is transferred across felt in parallel by conduction, radiation and gaseous conduction. A decrease of mean pressure reduces the gaseous conduction while the other two heat transfer mechanisms experience little change. Elimination of gaseous conduction decreases the effective thermal conduction by an order of magnitude. Hence, it plays a paramount role in the effective thermal resistance of felts at very low pressures.

The first step was to establish the thermal conductivity of gases for both the continuum and free molecule flow regimes. This result based on early work performed by Aerotherm is presented in Figure 3-18 where the ratio of the actual conductivity is the value of one atmosphere is plotted against a dimensional pressure, length, temperature parameter. This plot has been reworked to actual conductivity versus mean pressure (see Figure 3-19) by assuming a characteristic length and temperatures within the felt.

The next step was to correct felt data for gaseous conduction by accounting for this phenomenon. Figure 3-20 presents data on the thermal conductivity of glass wools. By applying the corrections of Figure 3-19, one constructes the continuous curve shown in Figure 3-18.

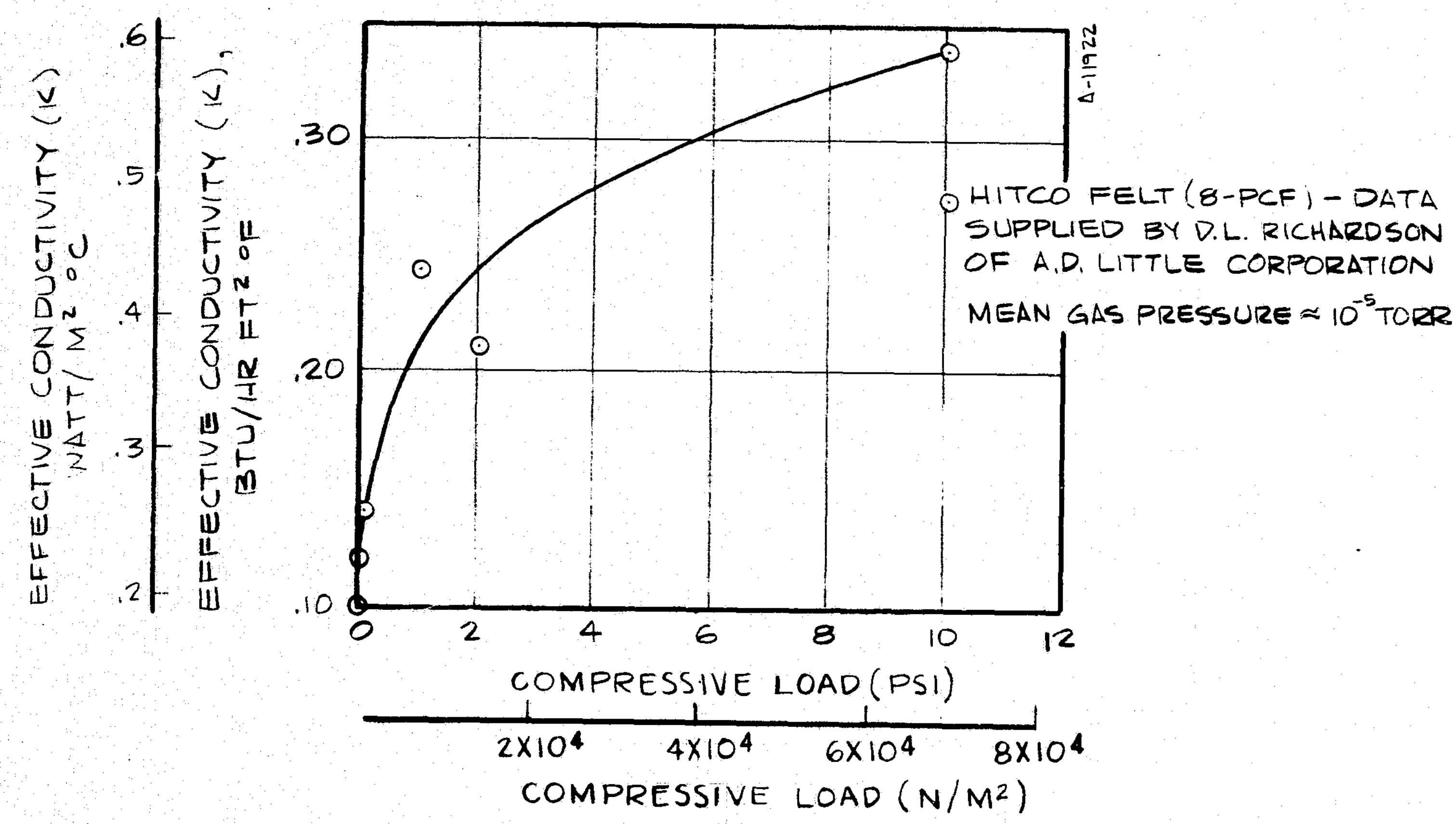



Figure 3-17. Variation of effective thermal conductivity of Hitco felt (8 PCF) with compressive load.

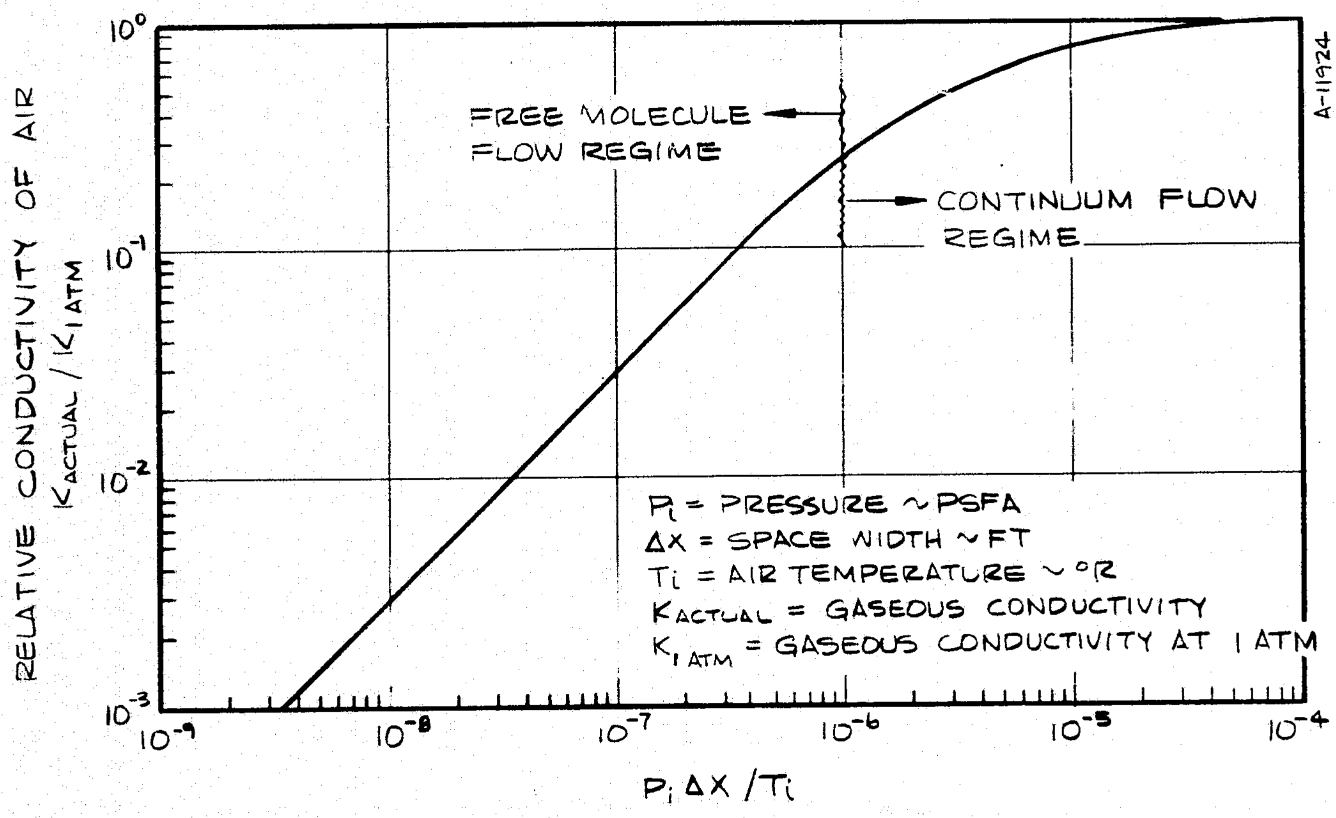



Figure 3-18. Relative thermal conductivity of air.

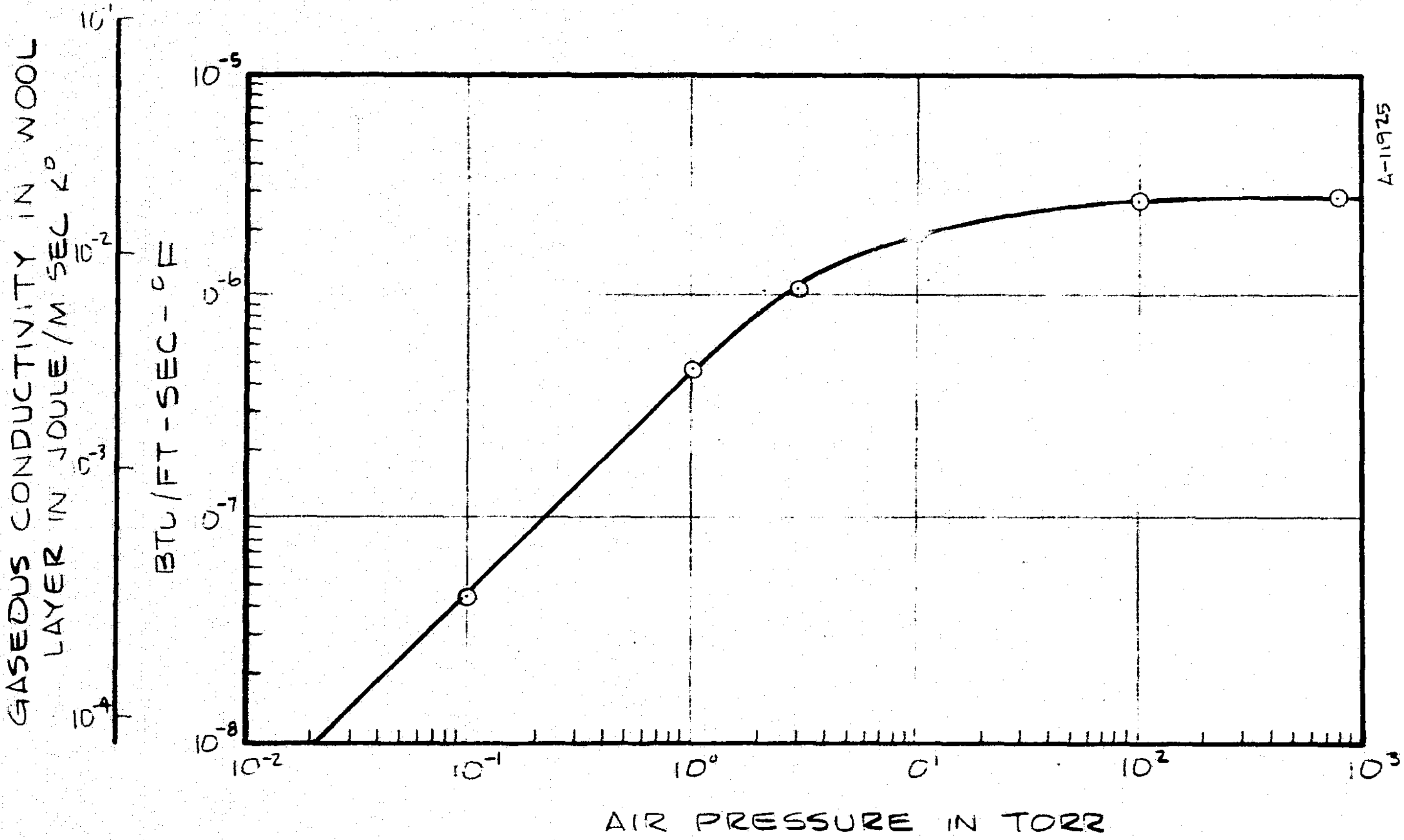



Figure 3-19. Gaseous conductivity in wool layer.

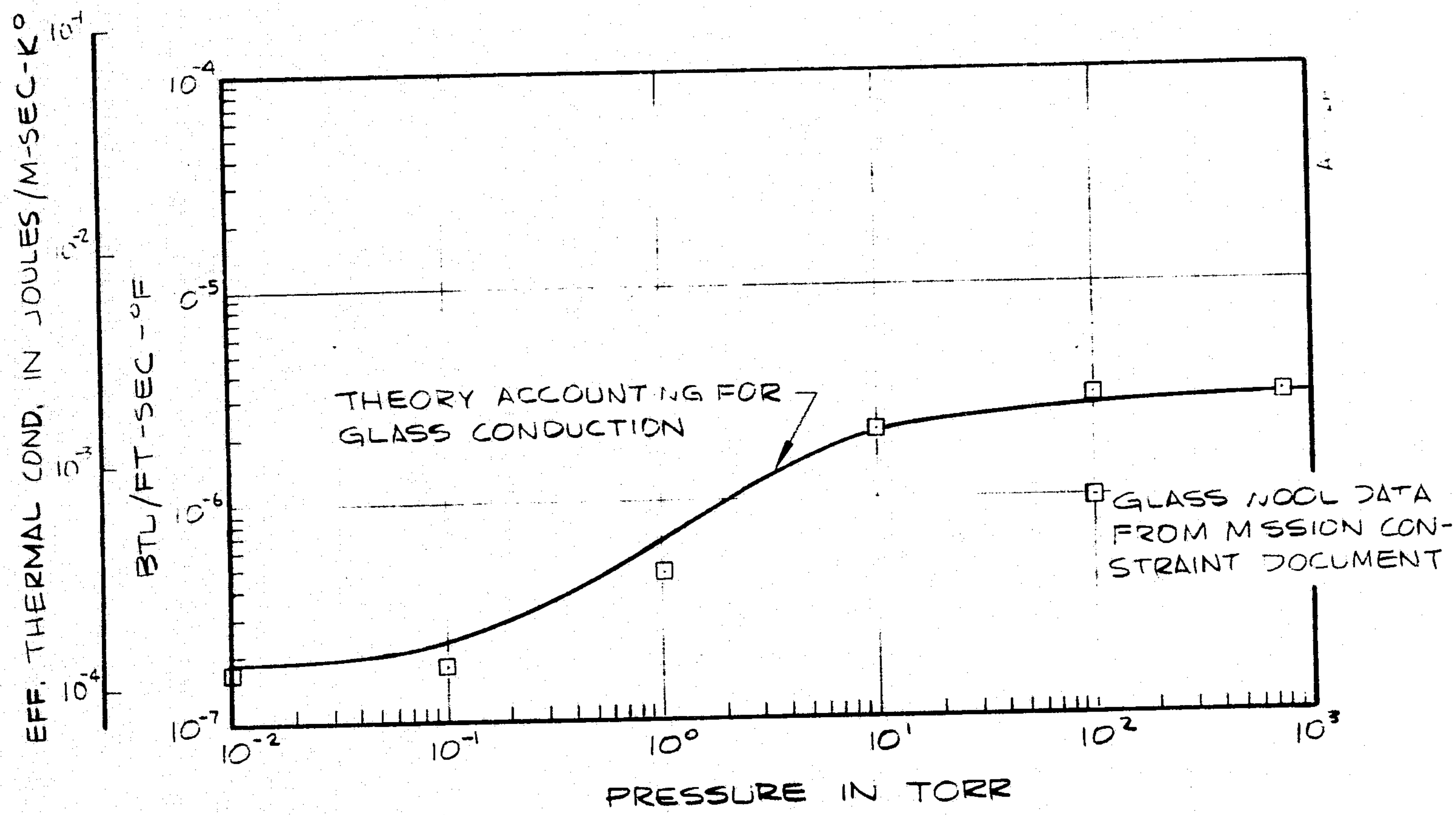



Figure 3-20. Variation of effective thermal conductivity of glass wool with pressure.

A few conductivity data points are presented for the wool for comparative purposes. It would appear that this correction suitably predicts the thermal conductivity of glass wool and accounts for the gaseous conduction of air. One should note that this correction is not trivial in that there is nearly an order of magnitude decrease in conductivity.

### 3.3.3 Micrometeoroid Protection Analysis

The micrometeoroid protection requirement is satisfied by the thermal overglove and pressure glove combination based on current data concerning the near earth micrometeoroid mass-flux relationship and a penetration analysis equation developed by NASA (Reference 8) for use in spacecraft design. The calculation was performed as follows:

For the lifetime of the EVA glove, it is desirable to have 0.99 probability of no damp-damaging impact (DI), thus

$$P_{DI} = 0.01$$

The surface area of an EVA glove is estimated at $0.1/m^2$ (1 $ft^2$) which is the effective vulnerable surface area. The typical length of an EVA task is estimated as 12 hours. Based on an estimated 6 flights per year and a lifetime of 5 years, a total exposure time of 300 hours is derived. From these values a meteoric surface impace flux, $\Phi$, is defined as $P_{DI}/A\theta$ where

$$A = 0.1/m^2$$

$$\theta = 300\ (3600) = 1.08 \times 10^6 \text{ seconds}$$

$$P_{DI} = 0.01 \text{ (Damaging Impacts)}$$

$$\Phi = 9.25 \times 10^{-8} \text{ DI/m}^2\text{-sec}$$

It is also possible to calculate, based on radar, photographic and spacecraft data the meteoric flux as a function of micrometeoroid mass. Graphically, such a plot appears in Figure 3-21.

For the given surface flux of $9.25 \times 10^{-8}$ impacts/$m^2$-sec a maximum meteoric mass of $2 \times 10^{-6}$ grams is indicated. Meteors of greater mass are beyond the chosen probability of hitting the glove within the given time span and meteors of smaller mass have sufficient probability of impact but less damaging potential. Now it remains to be determined if impact by such a micrometeoroid is damaging.

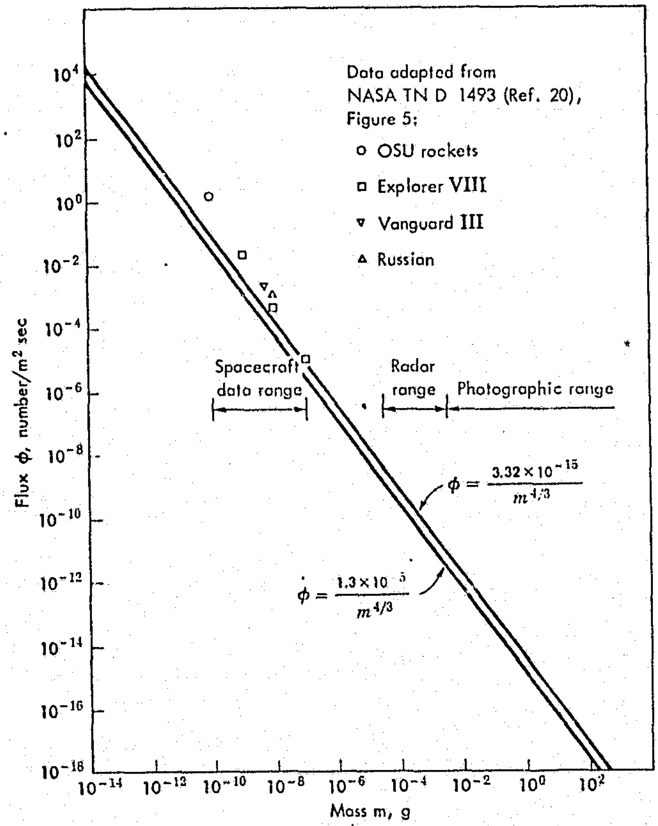



Figure 3-21. Meteoroid flux vs. mass.

To determine this an approximate penetration relation which has been used for meteoroid penetration analysis in the past was chosen.

$$\frac{D}{d} = 2.28 \left(\frac{\rho_m}{\rho_t}\right)^{2/3} \left(\frac{\nu}{c}\right)^{2/3}$$

where, $D$ = depth of penetration

$d$ = diameter of assumed spherical meteroid

$\rho_m$ = density of meteroid

$\rho_t$ = density of target material

$\nu$ = velocity of meteroid

$c$ = speed of sound in target material.

To estimate the velocity and diameter of the meteroid it is necessary to decide on its probable composition which is in turn a function of its origin. Two basic sources of meteoric debris in near earth orbit are known: Cometary, which composes 90 percent of the flux and asteroidal to which the remaining 10 percent is attributed. Accordingly, the assumption of a cometary particle density and velocity will be assumed (mass has already been developed from Figure 3-21). For both types of particles the values are listed below.

| | Density | Velocity |
|---|---|---|
| Cometary | 0.40 – 0.44 g/cm$^3$ | 30 mm/sec |
| Asteroidal | 2.7 g/cm$^3$ | 30 km/sec |

From the mass of 2 x $10^{-6}$ grams and the density a diameter of the meteorid is calculated as 2.3 x $10^{-2}$ cm.

The exact values for the speed of sound in the target material were unavailable and approximated by using the value for the speed of sound in nylon which is equal to 2591 m/sec. The density of the target material was taken as 1.05 gm/cm$^3$.

Using these values the depth of penetration is calcualted as 1.5mm (0.6 inch). This compares with the total glove cross section of approximately 3.7mm (0.15 inch) which includes both the thermal and pressure glove. Thus the protection afforded by the EVA glove is adequate for the anticipated environment over the exposure times expected with a 100 percent margin of safety.

## 3.4 MATERIALS SELECTION

Section 3.3.1 has reviewed the analysis conducted on the materials concepts explored in this program. The analysis resulted in establishment of a group of materials and concepts of known feasibility from which selections could be made. This section will first present the basis used for this selection process and the rationale employed. Second, the application of this process to all glove elements is presented.

### Selection Process Rationale

The basic considerations used in materials selection were determined by the primary design objectives. These design objectives included provision for

1. Passive thermal protection and abrasion resistance
2. Maximum mobility and tactility
3. Compatability with NASA/JSC flammability, outgassing, etc. requirements.

Within these design objectives two broad groups of materials were identified. The first group were those materials and concepts which had no major impact on the primary design objectives. The second group concerned those materials and concepts which potentially did have a significant impact upon the primary design objectives and for which a group of materials could be considered.

Establishment of the first group of materials resulted from the following factors:

1. Effort expended would result in a small payoff for the ultimate design objectives.
2. Materials within this class had a well defined history of availability and prior NASA use in identical applications.
3. Use of a new material offering limited potential improvement in areas outside the primary design objectives would require extensive requalification and negate the use of existing technology.

This group of materials offered little except potential program risk for deviation from identified materials.

Selection of materials within the second classification required use of a systematic, quantitative procedure for comparison of the various candidates. Review of the glove as a system resulted in the establishment of a ranking unique to each primary glove element. This approach permitted not only separating those criteria of importance for each glove element but

also emphasizing the relative importance of each criteria for the glove element under consideration. The resulting system consisted of first identifying the significant criteria for each glove element. Second, differentiating between the importance of various criteria was accomplished by assignment of relative weighting factors ranging from zero to ten. Each candidate within the list, for a given glove element, was then ranked for each criteria on a zero to ten scale. The ranking was then multiplied times the criteria weight. Finally, the weighted rankings for each material were summed and that material having the highest total was then identified. This approach resulted in continued emphasis on those criteria which offered the maximum potential for attainment of the primary design objectives. Additionally, if difficulties arose in availability, this approach provided a ready second choice among the materials considered.

Table 3-8 summarizes the criteria used and the weight assigned to those criteria for each glove element.

Group I Material Selection

As stated above, Group I materials were those which had only an indirect bearing upon the primary design objectives and for which no significantly better material candidates were identified. These materials are summarized in Table 3-9. It must be recognized that these selections resulted fom the integration of the total glove requirements and concurrent selections. For example, the multilayered insulation listed in Table 3-9 (aluminized mylar/polyester) could be listed in Group I materials because of the use of felts as the primary thermal protection concept as discussed in Section 3.3.1.

Group II Material Selections

The selection process described previously in this section was employed for choosing the remaining glove materials. Tables 3-10 through 3-14 illustrate the application of this selection process to the outer palm area of the glove. In this case, the optimum selection required not only consideration of a series of potential fabrics but also different potential coatings for each fabric. This approach permitted assessment of both the fabric and the coating employed on a comparative basis. For example, review of karma cloth through all three tables shows that its inherent safety, abrasion resistance and flexibility were reflected in the rankings independent of coating. Conversely, the inherently poor thermal response of karma cloth is also indicated regardless of coating. Considering all criteria, review of these tables reveals that a Kevlar 29 fabric offered the best solution and was consistently ranked higher than other candidates regardless of coating. Thus, the final

TABLE 3-8. GLOVE ELEMENT RANKING SYSTEM SUMMARY

| Criteria | Weight Assigned for Glove Element Listed.[1] | | | | | |
|---|---|---|---|---|---|---|
| | Outer Materials | | | Inner Materials | | |
| | Palm | Gauntlet | "Back of Hand" | Coated Fabric | Thread | Felt |
| Prior NASA Use or Recommendation | 10 | 10 | 10 | 10 | 10 | 10 |
| Abrasion Resistance[2] | 10 | 10 | 10 | 4 | 10 | N.A. |
| Strength | 2 | 2 | 2 | 1 | 4 | N.A. |
| Flexibility and Comfort | 6 | 6 | 6 | 2 | N.A. | 10 |
| Thermal | 2 | 1 | 1 | 2 | N.A. | 10 |
| Fabricability[3] | 10 | 10 | 10 | 10 | 10 | 10 |
| Safety | 6 | 6 | 6 | 6 | 1 | 10 |
| Friction[4] | 10 | N.A. | N.A. | 4 | N.A. | N.A. |
| Permeability | N.A. | N.A. | N.A. | 10 | N.A. | N.A. |
| Incompressability | N.A. | N.A. | N.A. | N.A. | N.A. | 6 |
| Optical | N.A. | 10 | 10 | N.A. | 1 | N.A. |

Notes: 1 Weight factor from one to ten

2 Against mating materials within glove or anticipated contacting surfaces outside glove

3 Within glove fabrication

4 Used as measure of tactility and ability to grasp tools, etc.

5 Outer material

N.A. — Not applicable for glove element listed.

TABLE 3-9. GROUP I MATERIAL SUMMARY

| Material | Rationale |
|---|---|
| Astro Velcro | Prior usage history<br>Approved by NASA (in closed condition)<br>Readily available<br>Meets all functional requirements |
| Double Aluminized Kapton Tape with Silicone Adhesive (both sides) | Meets all functional requirements<br>Readily available |
| Aluminized Mylar/ Polyester Nonwoven Separator | Limited use required in glove<br>Readily available<br>Prior usage history |
| Fire Retarded Neoprene Sealant | Prior NASA use/evaluation<br>Available<br>Compatible cure cycle developed |

TABLE 3-10a. PALM OUTER MATERIAL CANDIDATES WITH VITON COATING

| CRITERIA | WEIGHT FACTOR | FABRICS COATED WITH VITON | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TEFLON TFE-DARK | KEVLAR 29 | NYLON | DURETTE | PBI | NOMEX | ORTHO FABRIC | KYNOL-NOMEX | KARMA | GORETEX |
| PRIOR NASA USE OR RECOMMENDED | 10 | 1/10 | 10/100 | 1/10 | 10/100 | 10/100 | 10/100 | 10/100 | 1/10 | 10/100 | 10/100 |
| ABRASION | 10 | 7/70 | 8/80 | 5/50 | 3/30 | 4/40 | 3/30 | 9/90 | 1/10 | 9/90 | 8/80 |
| STRENGTH | 2 | 6/12 | 10/20 | 8/16 | 4/8 | 5/10 | 7/14 | 10/20 | 1/2 | 3/6 | 5/10 |
| FLEXIBILITY & COMFORT | 6 | 2/12 | 9/54 | 1/6 | 1/6 | 3/18 | 5/30 | 1/6 | 5/30 | 9/54 | 1/6 |
| THERMAL | 2 | 1/2 | 5/10 | 3/6 | 10/20 | 9/18 | 3/6 | 2/4 | 3/6 | 0/0 | 1/2 |
| FABRICATION | 10 | 7/70 | 8/80 | 6/60 | 6/60 | 4/40 | 7/70 | 8/80 | 4/40 | 7/70 | 6/60 |
| SAFETY | 6 | 2/12 | 9/54 | 3/18 | 7/42 | 5/30 | 8/48 | 8/48 | 4/24 | 10/60 | 8/48 |
| FRICTION | 10 | 0/0 | 5/50 | 3/30 | 3/30 | 3/30 | 5/50 | 1/10 | 5/50 | 5/50 | 1/10 |
| TOTALS | | 188 | 448 | 196 | 296 | 286 | 348 | 358 | 172 | 430 | 316 |

*Rating/rating X weight factor.

TABLE 3-10b. PLAM OUTER MATERIAL CANDIDATE, WITH FLUOREL COATING

| CRITERIA | WEIGHT FACTOR | FABRICS COATED WITH FLOUREL | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TEFLON TFE-DARK | KEVLAR 29 | NYLON | DURETTE | PBI | NOMEX | ORTHO FABRIC | KYNOL-NOMEX | KARMA | GORETEX |
| PRIOR NASA USE OR RECOMMENDED | 10 | 1/10 | 10/100 | 1/10 | 10/100 | 10/100 | 10/100 | 10/100 | 1/10 | 10/100 | 10/100 |
| ABRASION | 10 | 7/70 | 8/80 | 5/50 | 3/30 | 4/40 | 3/30 | 9/90 | 1/10 | 9/90 | 8/80 |
| STRENGTH | 2 | 6/12 | 10/20 | 8/16 | 4/8 | 5/10 | 7/14 | 10/20 | 1/2 | 3/6 | 5/10 |
| FLEXIBILITY & COMFORT | 6 | 2/12 | 9/54 | 1/6 | 1/6 | 3/18 | 5/30 | 1/6 | 5/30 | 9/54 | 1/6 |
| THERMAL | 2 | 1/2 | 5/10 | 3/6 | 10/20 | 9/18 | 3/6 | 2/4 | 3/6 | 0/0 | 1/2 |
| FABRICATION | 10 | 6/60 | 7/70 | 5/50 | 5/50 | 3/30 | 6/60 | 7/70 | 3/30 | 6/60 | 5/50 |
| SAFETY | 6 | 2/12 | 9/54 | 3/18 | 7/42 | 5/30 | 8/48 | 8/48 | 4/24 | 10/60 | 8/48 |
| FRICTION | 10 | 0/0 | 5/50 | 3/30 | 3/30 | 3/30 | 5/50 | 1/10 | 5/50 | 5/50 | 1/10 |
| TOTALS | | 178 | 438 | 186 | 286 | 276 | 338 | 348 | 162 | 420 | 306 |

TABLE 3-10c. PALM OUTER MATERIAL CANDIDATES WITH SILICONE COATING

| CRITERIA | WEIGHT FACTOR | FABRICS COATED WITH SILICONE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TEFLON TFE-DARK | KEVLAR 29 | NYLON | DURETTE | PBI | NOMEX | ORTHO FABRIC | KYNOL-NOMEX | KARMA CLOTH | GORETEX |
| PRIOR NASA USE OR RECOMMENDED | 10 | 1/10 | 10/100 | 1/10 | 10/100 | 10/100 | 10/100 | 10/100 | 1/10 | 10/100 | 10/100 |
| ABRASION | 10 | 7/70 | 8/80 | 6/60 | 3/30 | 4/40 | 3/30 | 10/100 | 1/30 | 10/100 | 8/80 |
| STRENGTH | 2 | 6/12 | 10/20 | 8/16 | 4/8 | 5/10 | 7/14 | 10/20 | 1/2 | 3/6 | 5/10 |
| FLEXIBILITY & COMFORT | 6 | 2/12 | 9/54 | 3/18 | 3/18 | 4/24 | 5/30 | 1/6 | 5/30 | 9/54 | 1/6 |
| THERMAL | 2 | 1/2 | 5/10 | 3/6 | 10/20 | 9/18 | 3/6 | 2/4 | 3/6 | 0/0 | 1/2 |
| FABRICATION | 10 | 7/70 | 9/90 | 8/80 | 8/80 | 5/50 | 8/80 | 9/90 | 4/40 | 6/60 | 7/70 |
| SAFETY | 6 | 2/12 | 9/54 | 3/18 | 7/42 | 5/30 | 8/48 | 8/48 | 4/24 | 10/60 | 8/48 |
| FRICTION | 10 | 2/20 | 10/100 | 6/60 | 5/50 | 5/50 | 10/100 | 2/20 | 10/100 | 10/100 | 2/20 |
| TOTALS | | 208 | 508 | 268 | 348 | 322 | 408 | 388 | 242 | 480 | 336 |

TABLE 3-11. OUTER FABRIC CANDIDATES RANKING*

| CRITERIA | WEIGHT FACTOR | FABRICS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TEFLON TFE-DARK | KEVLAR 29 | KEVLAR 49 | NYLON | DURETTE | PBI | NOMEX | ORTHO FABRIC | KYNOL-NOMEX | KARMA | GORETEX |
| PRIOR NASA USE OR RECOMMENDED | 10 | 1/10 | 10/100 | 10/100 | 1/10 | 10/100 | 10/100 | 10/100 | 10/100 | 1/10 | 10/100 | 10/100 |
| ABRASION | 10 | 9/90 | 8/80 | 8/80 | 6/60 | 3/30 | 4/40 | 3/30 | 10/100 | 1/10 | 10/100 | 8/80 |
| STRENGTH | 2 | 6/[illegible] | 10/20 | 10/20 | 8/16 | 4/8 | 5/10 | 7/14 | 10/20 | 1/2 | 5/10 | 5/10 |
| FLEXIBILITY & COMFORT | 6 | 9/5[illegible] | 5/30 | 5/30 | 3/18 | 3/18 | 4/24 | 5/30 | 8/48 | 5/30 | 2/12 | 8/54 |
| THERMAL | 1 | 2/2 | 5/5 | 5/5 | 3/3 | 10/10 | 9/9 | 3/3 | 2/2 | 2/2 | 0/0 | 1/1 |
| OPTICAL | 10 | 1/10 | 5/50 | 5/50 | 8/80 | 4/40 | 3/30 | 9/90 | 10/100 | 4/40 | 2/20 | 10/100 |
| FABRICATION | 10 | 7/70 | 9/90 | 9/90 | 8/80 | 8/80 | 5/50 | 8/80 | 10/100 | 4/40 | 1/10 | 7/70 |
| SAFETY | 6 | 2/12 | 9/54 | 9/54 | 3/18 | 7/42 | 5/30 | 8/48 | 8/48 | 4/24 | 10/60 | 8/48 |
| TOTALS | | 260 | 429 | 429 | 285 | 328 | 293 | 395 | 518 | 158 | 312 | 463 |

*Excluvive of palm and finger area.

TABLE 3-12. INNER FABRIC CANDIDATES RANKING

| CRITERIA | WEIGHTING FACTOR | NEOPRENE ON | | | | SILICONE ON | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | NOMEX | KEVLAR | NYLON | DACRON | NOMEX | KEVLAR | NYLON | DACRON |
| PRIOR NASA USE OR RECOMMENDED | 10 | 10/100 | 10/100 | 10/100 | 2/20 | 10/100 | 10/100 | 2/20 | 2/20 |
| ABRASION | 4 | 3/12 | 8/32 | 6/24 | 6/24 | 5/20 | 9/36 | 6/24 | 2/8 |
| STRENGTH | 1 | 4/4 | 4/4 | 4/4 | 4/4 | 4/4 | 4/4 | 4/4 | 4/4 |
| FLEXIBILITY & COMFORT | 2 | 5/10 | 8/16 | 10/20 | 10/20 | 7/14 | 9/18 | 10/20 | 10/20 |
| THERMAL | 2 | 3/6 | 5/10 | 3/6 | 3/6 | 3/6 | 5/10 | 3/6 | 3/6 |
| FABRICATION | 10 | 5/50 | 5/50 | 8/80 | 8/80 | 5/50 | 5/50 | 7/70 | 8/80 |
| SAFETY | 6 | 5/30 | 10/60 | 10/60 | 3/18 | 8/48 | 9/54 | 3/18 | 3/18 |
| PERMEABILITY | 10 | 5/50 | 5/50 | 5/50 | 5/50 | 1/10 | 1/10 | 1/10 | 1/10 |
| FRICTION | 4 | 9/36 | 9/36 | 9/36 | 9/36 | 10/40 | 10/40 | 10/40 | 10/40 |
| TOTALS | | 298 | 358 | 380 | 258 | 292 | 322 | 212 | 206 |

| CRITERIA | WEIGHTING FACTOR | VITON ON | | | | FLOUREL ON | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | NOMEX | KEVLAR | NYLON | DACRON | NOMEX | KEVLAR | NYLON | DACRON |
| PRIOR NASA USE OR RECOMMENDED | 10 | 10/100 | 10/100 | 10/100 | 2/20 | 10/100 | 10/100 | 2/20 | 2/20 |
| ABRASION | 4 | 3/12 | 8/32 | 6/24 | 2/8 | 3/12 | 8/32 | 6/24 | 2/8 |
| STRENGTH | 1 | 4/4 | 4/4 | 4/4 | 4/4 | 4/4 | 4/4 | 4/4 | 4/4 |
| FLEXIBILITY & COMFORT | 2 | 5/10 | 8/16 | 10/20 | 10/20 | 5/10 | 8/16 | 10/20 | 10/20 |
| THERMAL | 2 | 5/10 | 8/16 | 10/20 | 3/6 | 5/10 | 8/16 | 10/20 | 3/6 |
| FABRICATION | 10 | 5/50 | 5/50 | 7/70 | 8/80 | 4/40 | 4/40 | 6/60 | 7/70 |
| SAFETY | 6 | 10/60 | 10/60 | 3/18 | 3/18 | 10/60 | 10/60 | 3/18 | 3/18 |
| PERMEABILITY | 10 | 10/100 | 10/100 | 10/100 | 10/100 | 10/100 | 10/100 | 10/100 | 10/100 |
| FRICTION | 4 | 5/20 | 5/20 | 5/20 | 5/20 | 5/20 | 5/20 | 5/20 | 5/20 |
| TOTALS | | 366 | 398 | 376 | 276 | 356 | 388 | 286 | 266 |

TABLE 3-13. FELT CANDIDATES RANKING

| CRITERIA | WEIGHT FACTOR | FELTS | | | | | |
|---|---|---|---|---|---|---|---|
| | | PBI | DACRON | NOMEX | TEFLON TFE | KEVLAR | DURETTE |
| PRIOR NASA USE OR RECOMMENDATION | 10 | 10/100 | 10/100 | 10/100 | 1/10 | 10/100 | 10/100 |
| INCOMPRESSIBILITY | 6 | (6/36)* | 7/42 | 4/54 | 10/60 | (9/54) | (9/54) |
| FLEXIBILITY AND COMFORT | 10 | (10/100) | 8/80 | 10/100 | 9/90 | (10/100) | (10/100) |
| THERMAL | 10 | (10/100) | 9/90 | 8/80 | 7/70 | (8/80) | (8/80) |
| SAFETY | 10 | (10/100) | 8/80 | 9/90 | 9/90 | (9/90) | (9/90) |
| FABRICATION | 10 | (10/100) | 10/100 | 10/100 | 10/100 | (10/100) | (10/100) |
| TOTALS | | 536 | 492 | 524 | 420 | 524 | 524 |

*Parentheses represent estimates

TABLE 3-14. THREAD CANDIDATES RANKING

| CRITERIA | WEIGHT FACTOR | THREADS | | | | | |
|---|---|---|---|---|---|---|---|
| | | TEFLON TFE-DARK | KEVLAR 29 | NOMEX | GORETEX | GLASS | QUARTZ |
| PRIOR NASA USE OR RECOMMENDATION | 10 | 10/100 | 10/100 | 10/100 | 10/100 | 10/100 | 1/10 |
| ABRASION | 10 | 8/80 | 10/100 | 7/70 | 9/90 | 4/40 | 4/40 |
| STRENGTH | 4 | 4/16 | 10/100 | 7/28 | 6/24 | 8/32 | 8/32 |
| SAFETY | 1 | 7/7 | 10/10 | 10/10 | 7/7 | 7/7 | 7/7 |
| OPTICAL | 1 | 4/4 | 8/8 | 8/8 | 10/10 | 7/7 | 7/7 |
| FABRICATION | 10 | 7/70 | 10/100 | 10/100 | 8/80 | 5/50 | 5/50 |
| TOTALS | | 277 | 358 | 316 | 311 | 236 | 146 |

selection was based upon the comparative advantages of the various coatings. The final selection, silicone coated Kevlar fabric, was made due primarily to the combined friction and fabrication criteria. The comparative tactile improvement and known technology for coating after fabrication at room moderate temperatures of silicone coatings led to their final selection.

Table 3-12 summarizes the considerations which led to the selection of "Orthofabric" as the outer material for all glove elements other than the palm area discussed in the preceding paragraph. The considerations pertinent to these elements are reflected in the criteria column. It is to be noted in this column that the previosuly cited disadvantage of "teflon" fabrics for the palm area (poor frictional characteristics leading to difficulty in gripping tools, etc.) play no part. For the glove elements of concern in Table 3-11, where resistance to abrasion is of concern these factors made all the teflon fabrics of interest. As shown in this table, both the first and second choices employed teflon as the outer material. The dark PTFE candidate was ranked very low in optical properties. The inherent advantages of combining a white teflon (Goretex) outer fabric possessing desirable characteristics with a heat resistant fabric such as Nomex and Kevlar in a two-ply fabric led to the final selection of Orthofabric as the first choice for all outer materials other than the palm.

Selection of the coated inner materials provided another case where concurrent effects of coatings and fabrics had to be considered. The ranking of materials for the coated inner material is summarized in Table 3-12. The criteria listed reflect the concerns unique to this glove element. Here a new factor, permeability, played a major role in material selection while a previously major concern, thermal characteristics, was recognized but did not play a deciding factor. As shown, Kevlar fabrics coated with Viton, Flourel, and nylon coated with Viton and nonflammable neoprene again offered advantages over the other candidates when all criteria were concerned. Because little information is available on the coating Viton and Flourel on Kevlar or nylon and considerable amount of data has been collected on neoprene coated nylon, nonflammable neoprene coated nylon was selected for the inner shell. This amounted to selecting the third choice which had ascore of 380 compared to the highest value of 398, but more importantly, it involves working with a known commodity which will satisfy the glove requirements.

Threads constituted another area requiring application of this selection process. The results are summarized in Table 3-14. The criteria established reflect the comparatively minor parts played by threads in both the optical and safety (flammability) criteria. The

comparatively small amount of thread present minimized the safety concern. Optical concerns reflected the fact that although a very limited amount of the glove exterior surface area was covered by threads, the potential for affecting the thermal performance of the glove did exist. The importance of fabricability, abrasion resistance, strength and prior NASA use or recommendation led to the final selection of Kevlar 29 as the thread element.

The usefulness of this selection process in providing not only the primary choice but alternates as well was demonstrated in the selection of suitable felt materials. As discussed in Section 3.3.1, some difficulty was encountered in location of pertinent data for application of felts to being the primary thermal insulator for the glove. As indicated in Table 3-13, identification of the key criteria was essentially straightforward. However, a number of these criteria required estimation for some of the candidate felt materials. As indicated in Table 3-13, the first choice based on the ranking system employed was polybenzimidazole (PBI). Review showed, however, that this ranking was obtained largely upon estimated factors. Further, additional investigation showed that the availability of this material in a felt form was highly questionable. Review of the weighted rankings (Table 3-13) indicated that Nomex, Kevlar, and Durette felts could be considered with a decrease in ranked value of from only 536 (for PBI) to 524 for each of the alternative felts. Additionally, it was noted that the equivalency in ranking of the Kevlar and Durette systems was obtained again by a large number of estimated values. Accordingly, the Nomex felt system with no estimated values in its ranking could be selected for the further detailed investigation reported in Section 3.3.1. The results of these investigations were favorable and Nomex felt was selected as the primary insulation.

## 3.5 SAFETY CONSIDERATIONS

From the program inception Aerotherm recognized that a thermal glove totally optimized for functional acceptance would not be a valid solution if it failed to provide adequate safeguards to the user. Additionally safety must be assured to related personnel and systems over all defined mission segments, including contingency conditions. Alternately stated, the assurance of safety required continual consideration and implementation as part of the optimization process leading to the final glove design and prototype fabrication. Safety analysis required ascertaining the potential for failure in the following conditions:

1. The behavior of materials selected in anticipated environments

2. The potential for degradation of glove performance under possible anomalous conditions in use or fabrication
3. The potential for degradation/failure of related components
4. The inherent safety of the materials and concepts employed.

The initial criteria used as reference standards during the analysis portion of this program included those contained in NHB 8060.1, "Flammability, Odor and Offgassing Requirements and Test Procedures for Materials in Environments that Support Combustion (Reference 3). This document identifies two material groups. These groups include Group I materials defined as "...noncombustible or self extinguishing when tested for flammability properties in accordance with...Table 3-15." Group II materials are defined as "materials that do not meet the Group I flammability requirements. Group II materials shall not be used unless functional requirements preclude the use of Group I and...are specifically approved by the cognizant NASA center... Should it be imperative to use Group II materials in habitable environments, the functionally acceptable material with the lowest flame propagation rate and the lowest production rate for offgassed products shall be used."

Additionally, materials are classified by type based upon areas of use. The types considered are summarized in Table 3-16, taken directly from NHB 8060.1. Table 3-17 provides an extracted summary of the requirements for each test listed in Table 3-16 which is applicable to this program.

<u>Safety Considerations in Analysis and Concept Evaluation</u>

The initial consideration of safety was performed during the design concept selection and materials analysis phase. As stated in Section 3.3.1 during the initial listing of potential materials, one of the criteria used was flammability. This included consideration of flash point, flame point, offgassing (total organics and carbon monoxide) and flame propagation rate (if any). During this initial analysis the primary concern was directed towards two objectives: First, identify those materials whose flammability characteristics were poor as to constitute a hazard regardless of the glove element considered and secondly, identify the relative performance of materials.

Safety analysis also was employed in the evaluation of alternate designs for the thermal insulation concept selection. As noted in Section 3.3.1, one of the concepts explored was the use of powders as low conductivity materials. Analysis indicated that even if a totally

TABLE 3-15. MATERIALS USAGE TYPE AND GROUP CATEGORIZATION*

| MATERIALS USAGE CATEGORIZATION | GROUP I MATERIALS REQUIRED TESTS (SEE NOTE 1) | GROUP II MATERIALS (NASA CENTER APPROVAL FOR USE REQUIRED) REQUIRED TESTS (SEE NOTE 1) |
|---|---|---|
| Type A - Exposed Materials in the Crew Bay Environment | Test 1 or 4 or 5 (see note 4) Tests 6 and 7 | None (see note 5) |
| Type B - Special Applications and Minor Exposed Materials | Test 1 or 4 or 5 (see note 4) Tests 6 and 7 | Tests 2 and 3 and 6 and 7 |
| Type C - Low Pressure Oxygen Supply Materials | Test 1 or 4 or 5 Tests 6 and 7 (See Note 2) | Tests 2 and 3 and 6 and 7 (See Note 2) |
| Type D - Materials in High Pressure LOX/GOX/Systems | Tests 4 and 5 and 6 and 7 (See Note 2) (See Note 2) and 13 and 14 | None (see note 5) |
| Type E - Sealed Containers | Tests 1 and 9 | Tests 2 and 3 and 9 (See Note 3) |
| Type F - Vented Containers | Tests 1 and 8 and 6 and 7 | Tests 2 and 3 and 6 and 7 and 8 (See Note 3) |
| Type G - Materials Applications in Nonflight Equipment | Test 1 or 4 or 5 Tests 6 and 7 | Tests 2 and 3 and 6 and 7 |
| Type H - Material in Unpressurized Portions of the Spacecraft | Test 1 or 4 or 5 | Tests 2 and 3 |
| Type J - Materials in Combustion Supporting Environments Other than Oxygen | Test 15 | None (see note 5) |

NOTE:
1. End Item configuration-type test 10 or 11 and 12 or an analysis required for final materials acceptance for use in manned spacecraft except type H for which Test 12 is not required.
2. Tests 6 and 7 applicable to LOX systems which could affect crew atmosphere.
3. Tests 2 and 3 applicable to material selection and not End Item Sealed or Vented Container.
4. Both tests 1 and 5 are applicable to potting compounds and conformal coatings.
5. Normally, only Group I materials may be used in these applications. When Group II materials must be used, specific program office approval is required. The materials are then subjected to all the tests required for the Type application.

*Taken from NHB 8060.1, "Flammability, Odor, and Offgassing Requirements and Test Procedures for Materials in Environments that Support Combustion," NASA, February 1974, p. 2-4.

TABLE 3-16. NHB 8060.1 TEST AND REQUIREMENT SUMMARY FOR THERMAL GLOVE (Reference 1)

| Test Number | Test Title | Acceptability Criteria |
|---|---|---|
| 1 | Upward Propagation Test | Group I classification if noncombustible or self extinguishing before 6 inches are burned, burning time 10 minutes max.; no sparking, sputtering or dripping of flaming particles. If failed, perform Test 2 |
| 2 | Downward Propagation Rate Test | Performed to provide relative ranking for material review and selection |
| 3 | Flash Point and Fire Point Test | Candidate materials shall be acceptable for design if they exhibit a flash point above 400°F and a fire point above 450°F |
| 4 | Electrical Wire Insulation and Accessory Flammability Test | Not applicable |
| 5 | Electrical Connector Potting and Conformance Coatings Flammability Test | Not applicable |
| 6 | Odor Test | Average rating of 2.5 or lower is acceptable |
| 7 | Determination of Offgassing Products and Carbon Monoxide Test | Total organics, excluding water, shall not exceed 100 micrograms per gram of material; carbon monoxide shall not exceed 25 micrograms; inorganic gases shall be evaluated for potential toxicity levels |
| 8 | Flammability Test for Materials in Vented Containers | Not applicable |
| 9 | Electrical Overload Test for Sealed Containers | Not applicable |
| 10 | Guidelines for Simulated Panel and Assembly Flammability Test | Not applicable |
| 11 | Guidelines for Simulated Crew Bay Configuration Flammability Verification Test | Not applicable |
| 12 | Guidelines for Total Spacecraft Offgassing Test | Not applicable |
| 13 | Ambient Liquid Oxygen and Pressurized Liquid and Gaseous Oxygen Mechanical Impact Tests | Not applicable |
| 14 | Gaseous Oxygen Impact Test | Not applicable |

## TABLE 3-17. TEST DATA SUMMARY FOR MATERIALS OF INTEREST

| MATERIALS | ENVIRONMENT | | FLAMMABILITY | | | ODOR | OFFGASSING | |
|---|---|---|---|---|---|---|---|---|
| Generic Type and Form | Chamber Pressure (psi) | Oxygen Pressure (psi) | Flash Point (°F) | Flame Point (°F) | Propagation Rate (inch/sec) | Average Rating | CO (μgm/gm) | Total Organics (μgm/gm) |
| **Aramid** | | | | | | | | |
| Kevlar 29 Fabric | 12.0 | 2.5 | | | | | 0.4 | 0.0001 |
| ↓ | 12.0 | 2.6 | | | | 14 | | |
| | 10.0 | 3.1 | | | 0.014 | | | |
| | 14.5 | 3.5 | >990 | >990 | 0-0.250 | | | |
| | 12.0 | 2.6 | | | | 10 | 0.5 | 0.0001 |
| Kevlar 49 Fabric | 6.2 | 4.3 | >600 | >600 | 0.450 | | | |
| **Amide** | | | | | | | | |
| Nomex Fabric | 5.0 | 5.0 | >600 | >600 | | 7-19 | 0.6 | 0.0001 |
| ↓ | 16.5 | 16.5 | >400 | >400 | 0.250 | | | |
| Nomex Felt | 12.3 | 2.6 | | | | 8 | | |
| ↓ | 12.0 | 2.5 | | | | | 0.7 | 0.0002 |
| **Silicone Elastomers** | | | | | | | | |
| RTV-108 | 5.0 | 5.0 | >400 | >450 | | 13 | 0.2 | 0.0250 |
| ↓ | 6.2 | 6.2 | >600 | >600 | 0.095 | | | |
| RTV-615 | 5.0 | 5.0 | | | | 7-8 | 0-2.2 | 0.0003 |
| RTV-615 & SS 4155 Primer | 5.0 | 5.0 | >540 | >540 | 0.130 | 14-17 | | |
| **Polyester** | | | | | | | | |
| Mylar | 5.0 | 5.0 | >420 | >420 | | 17-25 | 0.3 | 0.0003 |
| ↓ | 16.5 | 16.5 | | | 0.457 | | | |
| Mylar (Aluminized) | 6.2 | 6.2 | | | 1.250 | | | |
| **Fluorocarbons** | | | | | | | | |
| Teflon (FEP) | 6.0 | 6.0 | >480 | >480 | 0.000 | | | |
| ↓ | 5.0 | 5.0 | | | | 5 | 0.1 | 0.0001 |
| | 6.2 | 6.2 | >600 | >600 | | | | |
| Teflon Felt | 5.0 | 5.0 | | | | 2 | | |
| ↓ | 14.7 | 14.7 | | | 0-0.016 | | | |
| Teflon (TFE) | 5.0 | 5.0 | | | | 7-12 | 0.1 | 0.0000 |
| ↓ | 6.2 | 6.2 | >600 | >600 | 0.000 | | | |
| Teflon Fabric (White)* | 6.2 | 6.2 | >600 | >600 | 0.000 | | | |
| | 5.0 | 5.0 | >600 | >600 | | 9 | 0.7 | 0.0034 |
| **Elastomers** | | | | | | | | |
| Viton | 5.0 | 5.0 | | | | | 1.0 | 0.0330 |
| | 6.2 | 6.2 | | | 0.000 | | | |
| ↓ | 16.5 | 16.5 | | | 0-0.026 | | | |
| Fluorel | 5.0 | 5.0 | | | | 26 | 0.0 | 0.0001 |
| ↓ | 16.5 | 16.5 | >600 | >600 | 0.000 | | | |
| Neoprene | 14.7 | 14.7 | | | 0.000 | | | |
| ↓ | 5.0 | 5.0 | | | | 13-23 | 1.9 | 0.0001 |
| **Polyimide** | | | | | | | | |
| Kapton Film | 16.5 | 16.5 | >990 | >990 | | | | |
| Kapton (Aluminized) | 5.0 | 5.0 | | | 1.66 | 14-18 | 23.0 | 0.0020 |
| **Nylon** | | | | | | | | |
| Nylon Fabric | 5.0 | 5.0 | | | | 12-24 | 2.4 | 0.0003 |
| ↓ | 6.2 | 6.2 | >600 | >600 | 0.084 | | | |
| Nylon Fabric, Neoprene Coated** | 5.0 | 5.0 | | | 0.400 | 13 | | |
| Nylon Fabric, Viton Coated | 6.2 | 6.2 | >600 | >600 | 0.130 | | | |
| **Miscellaneous** | | | | | | | | |
| Kevlar 29 Fabric, Fluorel Coated | 14.5 | 3.5 | >990 | >990 | 0.000 | | | |
| ↓ | 12.3 | 2.6 | | | | 6 | | |
| | 12.0 | 2.5 | | | | | 0.1 | 0.0001 |
| Betaglass, Teflon and Fluorel | 6.0 | 6.0 | >600 | >600 | 0.000 | | | |
| ↓ | 5.0 | 5.0 | | | | 17 | 0.2 | 0.0002 |
| Betaglass, Polyester, Fluorel | 5.0 | 5.0 | | | | 7 | 0.1 | 0.0000 |
| ↓ | 6.0 | 6.0 | >600 | >600 | 0.373 | | | |
| Mated Astrovelcro | 6.2 | 6.2 | | | 0-0.035 | | | |
| White Nylon Velcro | 5.0 | 5.0 | | | | | 0.7 | 0.0001 |
| ↓ | 16.5 | 16.5 | >400 | >400 | 2.000 | | | |

* [illegible] Goretex

**Considered to be not flame retarded. WSTF 74-5073 reported 0.5 in/sec propagation rate (with self-extinguishment), 0.1 - 1.0 odor rating, 0.3 μgm/ym CO and 2.0 μgm/gm total organics for the flame resistant form.

noncombustible material were employed, in the event of glove rupture from an anomalous event, the potential for contamination of related systems and components could not be avoided. This concept was accordingly eliminated. Additionally, the Fibertran concept was eliminated partially because of the potential flammability of some of the standard component materials. Further, a key element of an "imporved" Fibertran would have entailed dependence of its thermal insulating characteristics on a low emissivity coating. This was considered unacceptable for a component potentially subject to high abrasion use.

Safety Considerations in Material Selection and Utilization

With the materials, thermal and micrometeoroid analyses concluded, detailed selection of the final material types and concepts could be implemented. This required consideration of safety in a much broader context than the flammability criteria employed in the analysis phase described above. Specific safety concerns addressed during the selection phase and utilization from a design standpoint included the following:

1. Maximum utilization of known materials (where suitable for the concept selected) to fully utilize previous developments in safety standards (Kevlar coated with flame retarded neoprene, etc.).
2. Recognition of the potential failure modes which could arise due to the environments as defined in the mission constraints (use of silicone adhesives and coatings to assure low temperature flexibility without cracking).
3. Recognition that over the anticipated life unusual conditions could occur where the glove might contact sharp or highly abrasive surfaces and objects.
4. Assure that the fabrication techniques employed would not degrade the glove concept or materials employed.
5. Replacement of selections made when evidence of inadequacy was obtained.
6. Implementation of design concept changes when a potential for system degradation was identified.
7. Final review of selections for "flammability" areas of concern as shown in Table 3-17.

In Table 3-17, wherever data generated in pure oxygen tests was located it was chosen and is listed over similar data developed in mixed nitrogen and oxygen environment tests.

Additionally included in Table 3-17 are offgassing test results for 155°F exposure. Information on related materials and components of materials was also entered in this table.

Upgraded Systems Safety Capability

An integral part of the systems safety portion of this program was to establish the capability to fulfill two objectives:

1. Accommodate changes within the program on a portotype level.

2. Permit upgrading goals on air operational levels.

If one is to achieve the second objective it requires the capability to understand, analyze and develop solutions incorporating safety considerations should potential changes at a component, systems, mission environment, mission profile levels or contingency conditions arise. Should none of these changes occur, upgrading would obviously be simplified. As discussed above, overall systems safety trade-off analysis, assessments, analysis of interface requirements and environmental extremes have been used in selection of both component materials and design concepts. Upgraded, more formalized analyses and considerations will, when required, be readily implemented.

## 3.6 QUALITY ASSURANCE

The quality program implemented throughout the glove development effort had as its basic objective the assurance that the end item conformed to the design requirements at a component and systems level. Accomplishment of this task required verification of procured components, fabrication and processing of these components and verification of the end item for conformance. Each of these quality program elements will be reviewed in this section.

Procured Component Verification

Verification of procured components was assured by first reviewing purchase orders. This review was conducted to establish that the exact materials and their requirements were stated on the purchase order in conformance with the design callout. Secondly, all ordered materials were inspected for conformance to the purchase order requirements and that test reports or certifications were received from the supplier. Thirdly, when a discrepancy was noted or suspected, an investigation was performed to obtain resolution. Typical examples include initially not receiving certificaitons for the Kevlar thread and a suspected discrepancy in the Orthofabric weave construction. In the former case, the certification was obtained, and in the latter case an investigation showed that in fact the correct weave construction was received.

Fabrication Verification

Verification of the fabrication and processing consisted of two activities. First, the potential for degradation of properties or characteristics of the components as a result of the processing employed was assessed. Typical examples include development of a suitable cure cycle for the fire retardant neoprene thread sealant and assessment of potential long term effects of heat on the dimensional stability of the Nomex felt. Results of these assessments are reported in Sections 3.3.1 and 3.5, respectively. Second, review of documentation covering all fabrication operations and assembly was completed. This review was conducted to assure that complete definition of the required operations was provided and that the callout of required materials was correct. This review assured not only that correct materials and procedures were employed but also that, if required, the same end item could be reproduced.

End Item Verification

A final review of the completed glove was performed to assure and verify the high standards of workmanship and quality required. Additionally, mobility, heat transfer and leak-rate tests were performed to verify the glove physical characteristics at the time of delivery. The left hand of the final pair of delivered gloves is shown in Figure 1-1.

# SECTION 4

# FABRICATION

Each thermal glove was fabricated as three separate gloves (shells) which became united during fabrication. The inner shell was secured to the pressure glove by Velcro bonded to the finger tip and knuckle areas of the two gloves.

Appendix A includes complete glove fabrication procedures, materials, and assembly drawings.

# SECTION 5

# TESTING AND EVALUATION

A number of tests were performed to evaluate the performance of the thermal glove I and IA. The details of the various tests are presented in the Test Plan and Procedure document (Reference 9), and owing to their length are not presented here. The basics of the various tests are presented for completeness herein. The following sections cover tests made on Glove I before and after 100,000 man cycles and on Glove IA.

Tests were performed to measure heat transfer rates, temperatures, mobility, tactility, and glove leak rates. The results of these tests are discussed in the following sections.

## 5.1 THERMAL TESTS

It was the primary objective of the thermal test to measure the inside pressure glove/skin temperature when the exterior of the glove was held at one of the design conditions. Originally, these tests were to be performed at NASA (Johnson Space Center); however, owing to unforseen problems with the test facility, the tests could not be performed as scheduled. Hence, Aerotherm developed their own experiment to evaluate the protective ability of the glove. Such tests could only be run at atmosphere pressure instead of orbital altitude pressure ($<10^{-4}$ torr).

Testing of the insulative abilities of the thermal gloves or mockups of the fingers was conducted at four points in the course of this project. In all cases the test procedure was essentially the same and the results were modeled using the SITT program to confirm the general profile of the experimentally derived skin temperature response curves and the adequacy of the code on predicting the time to failure for the layup. The failure condition was defined as any case in which the skin surface temperature exceeded 43.3°C (110°F) or by the skin temperature dropping below 10°C (50°F) after three minutes had elapsed of firmly gripping a 93.3°C (200°F) or -129°C (-200°F) surface respectively. It was established theoretically that the hot case was more critical of the hot/cold bar testing. Hence, owing to limited time and that heat transfer tests were not scoped into the program, only the hot bar tests were performed. Because of the roughly order of magnitude difference between the thermal conductivities of the

felt insulator at pressures below $10^{-3}$ torr and at one atmosphere, the time for the epidermis to reach 43.3°C (110°F) varied significantly between the experimentally tested one atmosphere case of that response expected in a hard vacuum. This conductivity change is shown graphically in Figure 5-1. In both pressure regimes the primary mode of heat transfer in felts is conduction with the gaseous contribution being the dominant and critical factor on the one atmosphere case.

Laboratory testing proved to be impossible for multilayer insulators. Tests could only be run for several seconds before the 43.3°C (110°F) skin temperature was surpassed as the change in thermal conductivity between one atmosphere and vacuum condition is even more pronounced than in the case of the felts as demonstrated in Figure 5-2.

The glass surface temperatures were evaluated by the SITT code. The appropriate thermal conductivities for the laboratory glove layup were used along with the recorded thermal boundary conditions consisting of the initial temperature of the layup and the hot bar surface temperature time history. Based on these reports the computer code then calculated a temperature profile at the epidermis which could be compared with that actually measured by a thermocouple on the skin surface during the test. After the data had been analyzed then the code could be rerun with thermal conductivities based on orbital configuration variables which remained unchanged for atmospheric and vacuum conditions were the thicknesses, densities and surface properties of the layup materials and the dermal tissue model.

Experimental Technique

The experiment was designed to approximate as closely as possible the thermal environment the actual glove was subject to with the obvious exception of the vacuum conditions. The glove was donned prior to the start of the test and internal temperature monitored with a thermocouple until it had stabilized. Typically, this was between 33.3°C (92°F) and 35.0°C (95°F) depending on the placement of the thermocouple, with the finger tips being cooler than the palmar areas. The hot bar was simulated with a flask of boiling water which, due to the effect of the wall thickness, maintained a outside surface temperature in the neighborhood of 77°C (170°F) to 82°C (180°F) throughout the test. To help replace heat loss to the glove during the test the flask was kept on a hot plate and insulated against heat loss to the environment.

A record of the internal temperature of the glove was kept at 15 second intervals for the first minute and 30 second intervals thereafter through the use of a stopwatch and tape

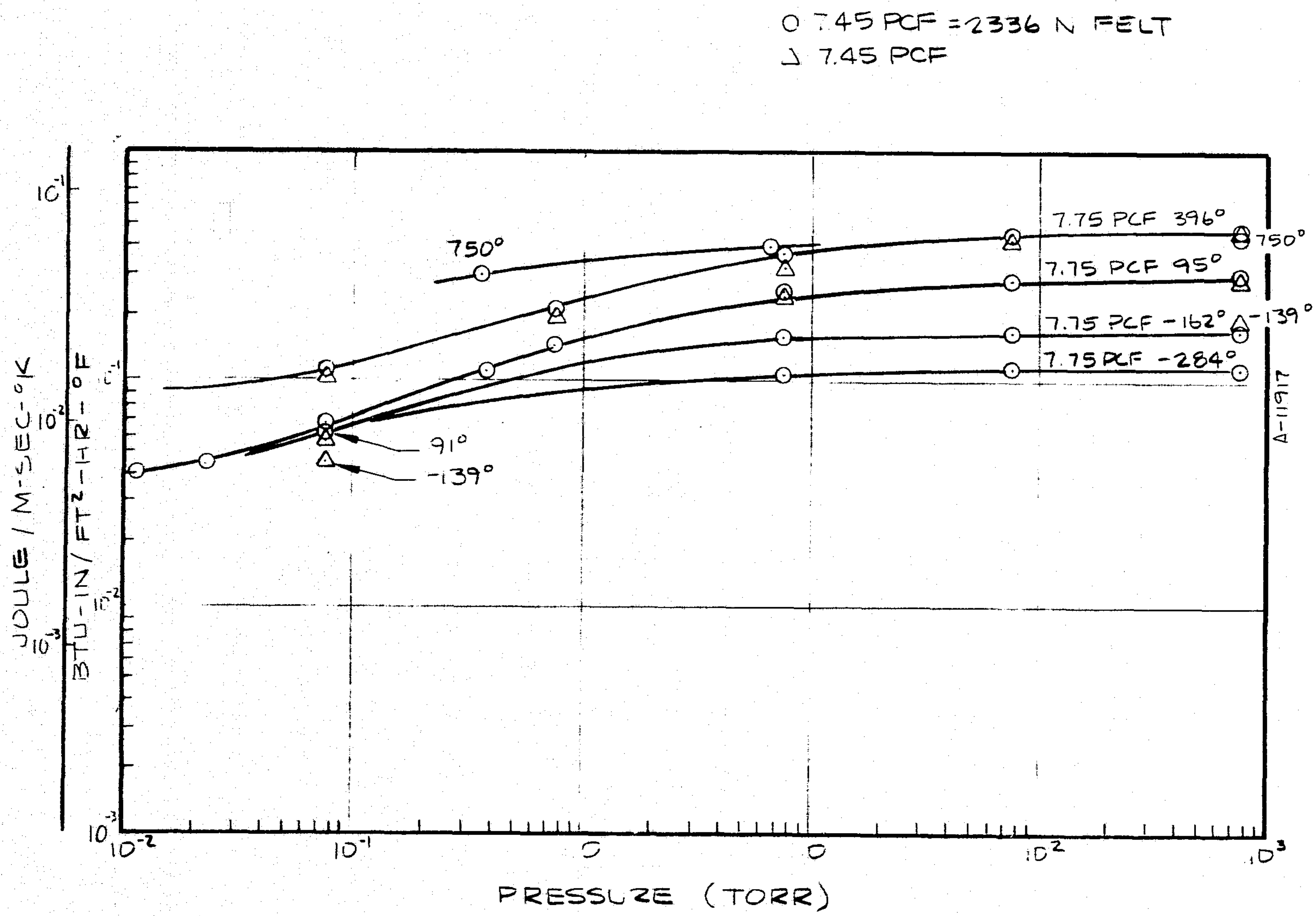



Figure 5-1. Variation in conductivity of Nomex felt with ambient pressure.

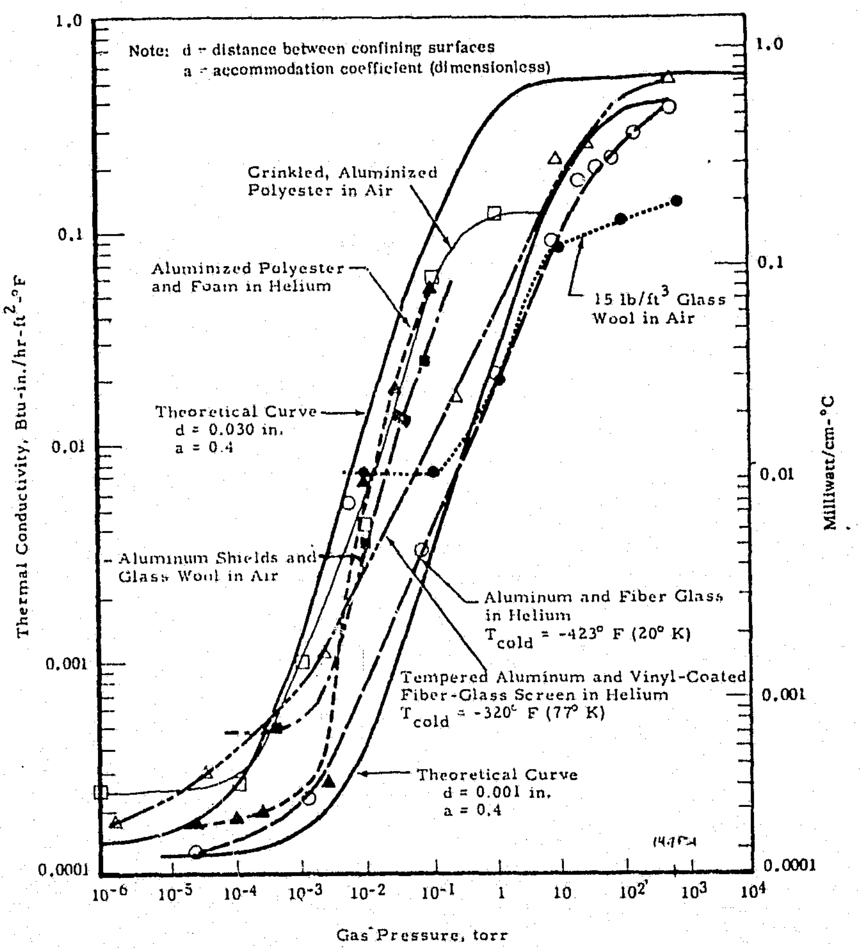



Figure 5-2. Effect of gas pressure on thermal conductivity. (Reference 12).

recorder. Additionally, the initial and final water temperatures and the final external flask temperatures were measured. The initial flask outside temperature varied rapidly immediately after contact with the thermal glove and was not measured; consequently, the surface temperature profile during the test was estimated using the initial and final water temperatures and the final measured temperature drop across the walls of the flask. This estimate when input into the computer model resulted in excellent agreement as shown earlier in Figure 3-3.

The copper-constantan thermocouple used a 0°C (32°F) reference bath and its output was monitored with a digital voltmeter. The thermocouple zero reading was checked before and after each test and the thermocouple voltage was converted to temperature using ASTM tables (Reference 11).

For each test the skin surface temperature was monitored at one location inside the glove with the test subject concentrating on maintaining a continuous firm grip pressure on the flask over the thermocouple. A series of tests included temperature histories of the thumb, palm and the index or middle finger. Occasionally, a location was tested twice to insure reproducibility of data or to examine a specific area in question.

The first series of tests was directed at establishing the interior response of the hand tissues which defines the backwall coefficient in the SITT computer program. The results of these tests as well as a discussion of how the backwall condition was derived from the experimental data appears in Section 3.3.2.

The layup that was tested in this series was fabricated from Kevlar fabric, 3.18mm (0.125 inch) thick Nomex felt and ripstop nylon and was worn over the GFE pressure glove. The thickness of felt used in this one series was greater than that used in the subsequent series of tests. This resulted in a slower temperature rise inside the glove and hence allowed for more precise computer modeling of the temperature response and a more accurate definition of the backwall condition.

The second series of tests involved an attempt to determine the effectiveness of placing a layer of aluminized mylar just below the outer fabric layer to shield against radiant heat transfer through the adjacent optically translucent felt layer.

The third series of tests was concerned with establishing a baseline thermal performance for the phase I or IA pressure and thermal glove combination prior to the 100,000 cycle life test. The layup tested was sized for use in a vacuum and thus was thinner than necessary for adequate protection in a one atmosphere environment. It consisted of a layer of silicone

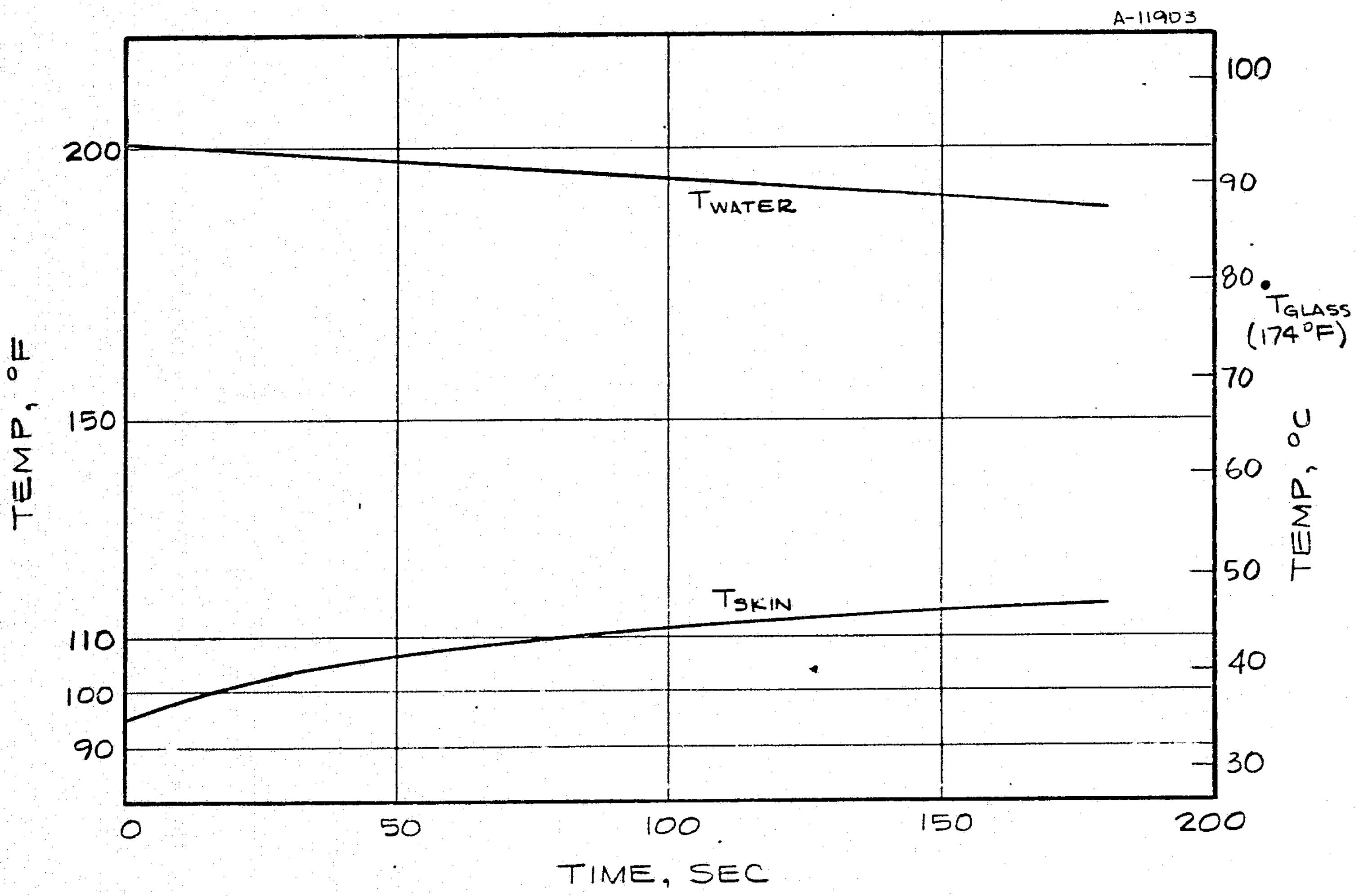



Figure 5-3. Skin temperature responce of thumb, pri-life test.

coated kevlar, backed by a radiation barrier of double aluminized mylar which overlayed a 2.29mm (0.09-inch) thick Nomex felt primary insulator. Finally, a layer of neoprene coated ripstop nylon acted as a gaseous barrier at the inside of the thermal glove.

The results of this testing are plotted in Figures 5-3 through 5-10. The curves are characteristic of the predicted responses with the internal temperature rising rapidly on initial hot surface contact with the slope of the curve becoming more gradual with time as the thermal gradients are reduced and the heat is conducted away through the dermal layers.

It is clear in these figures that the thumb and middle fingers have not reached stability by the end of the three minutes pointing out the transient nature of the response. The palmar temperature history shows only a linear temperature increase and thus is already close to steady state condition. The difference in the palmar and finger response was primarily the result of two factors. Firstly, the fingers experienced a greater loading (force/unit area) when the flask was held and experienced a greater degradation of the felt's thermal conductivity. Secondly, the palm area has a greater volume of tissue and thus an increased ability to transport heat from the contact area when compared with the finger, especially when high surface pressures close off blood flow through surface capillaries.

These same trends were seen on the post-life test results which are plotted in Figures 5-6 through 5-10. This series was more extensive than that of the pre-life test as a result of efforts to locate "hot spots" which would indicate failure or serious degradation of the insulator.

The pre- and post-life test results for the thumb appear in Figures 5-3, 5-6, and 5-7. Prior to the life test, the 43.3°C (110°F) internal temperature limit was reached 80 seconds into the test. During the two post-life tests, the corresponding times were 90 seconds and 70 seconds respectively resulting in no degradation of insulation during life tests.

It may be recalled that the design condition is 180 seconds, but in a vacuum. Owing to the large change in the thermal conductivity at reduced pressures, 80 seconds to failure time is considered guite good and the identical layup results in a temperature of 41.2°C (106.2°F) at the end of 5 mintues for vacuum conditions.

The correspondence between the pre-and post-life test middle finger temperature histories by comparison is quite poor with the earlier test measuring 43.3°C (110°F) at 120 seconds and the later one at 90 seconds. Inspection of the thermal glove after life tests showed no evidence of problems with the felt insulator but the single layer of aluminized mylar had been destroyed. The loss of MLI was not expected to be the major source of the

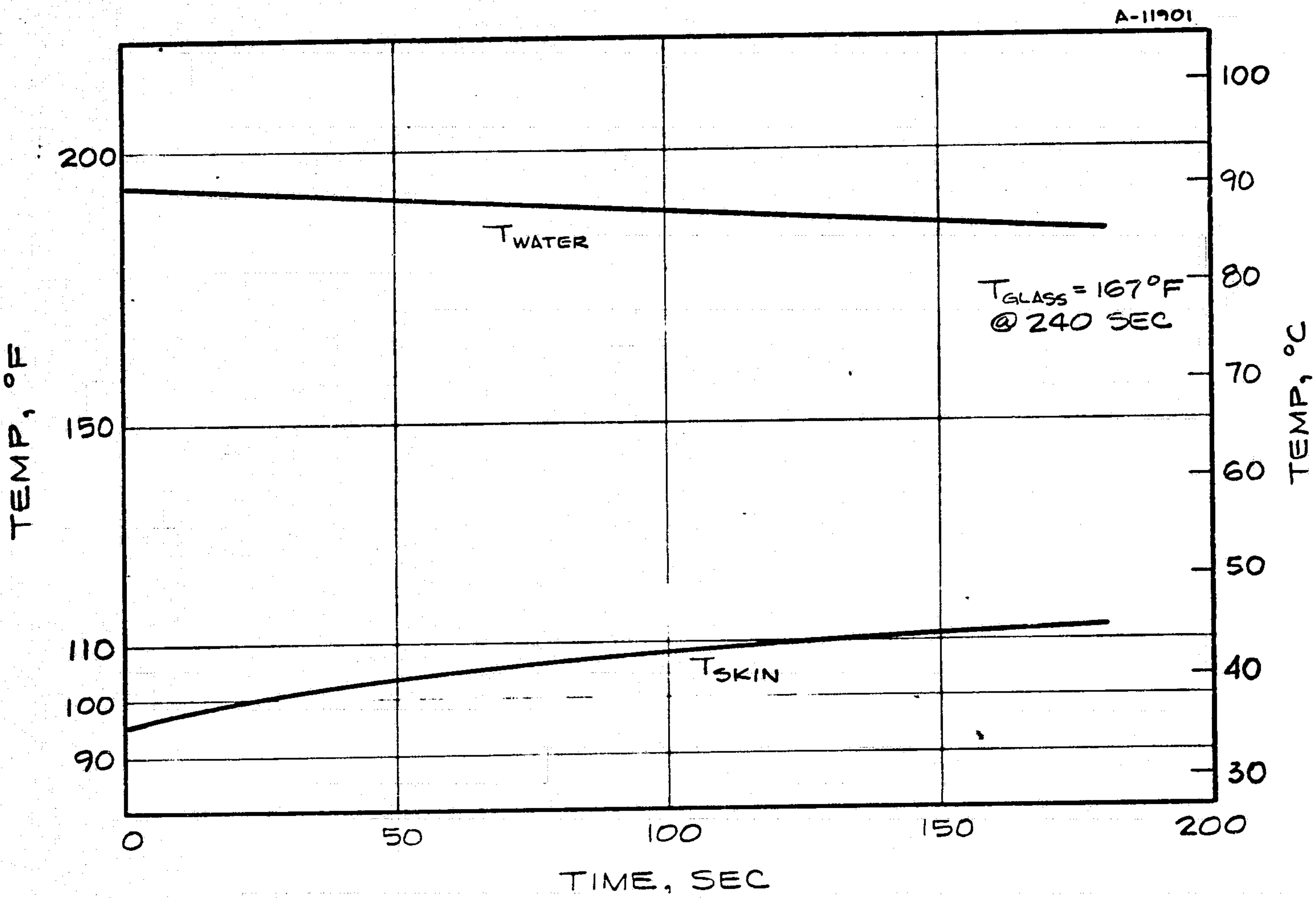



Figure 5-4. Skin temperature response of middle finger, pre-life test.

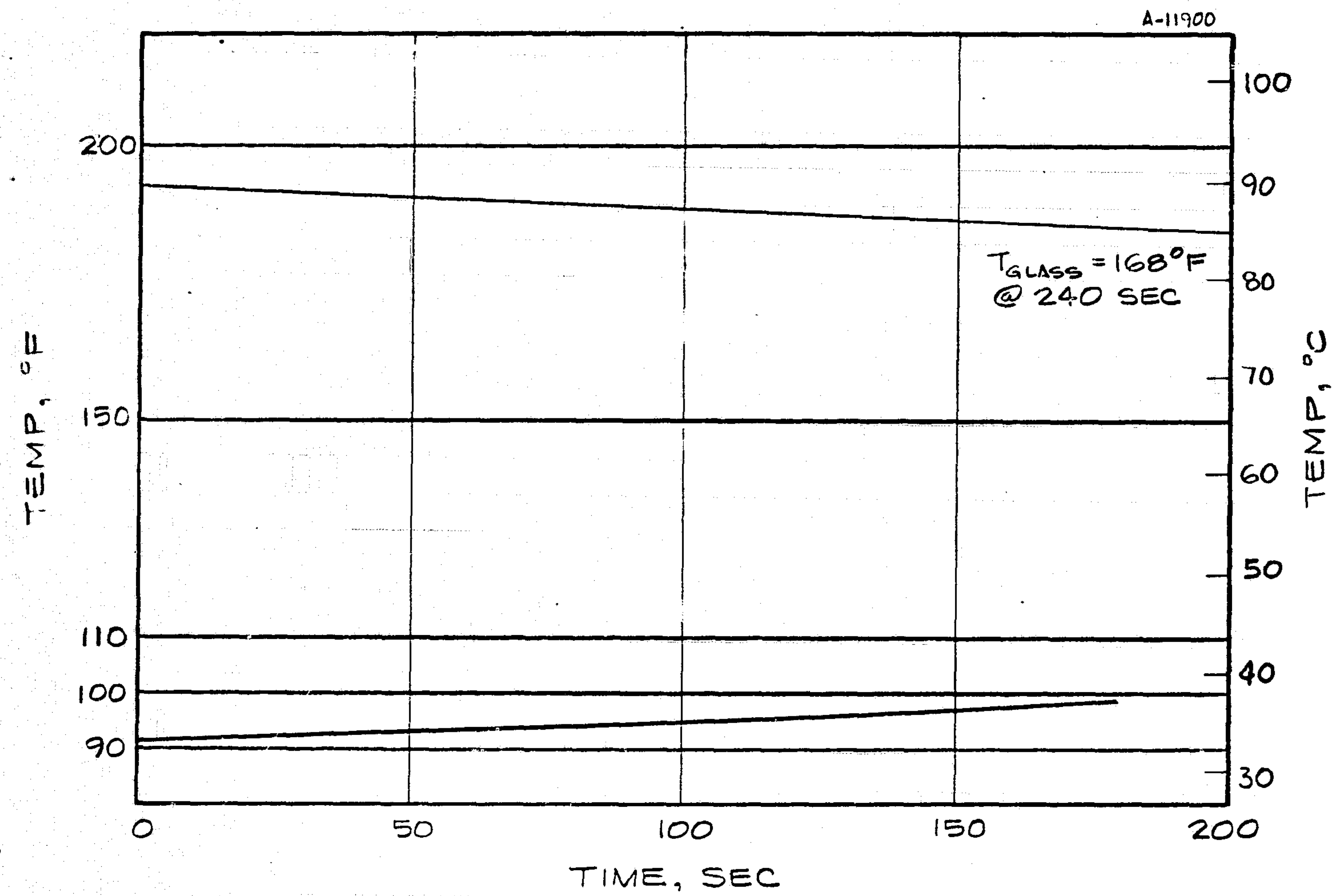



Figure 5-5. Skin temperature response of palm (under support bar), pre-life test.

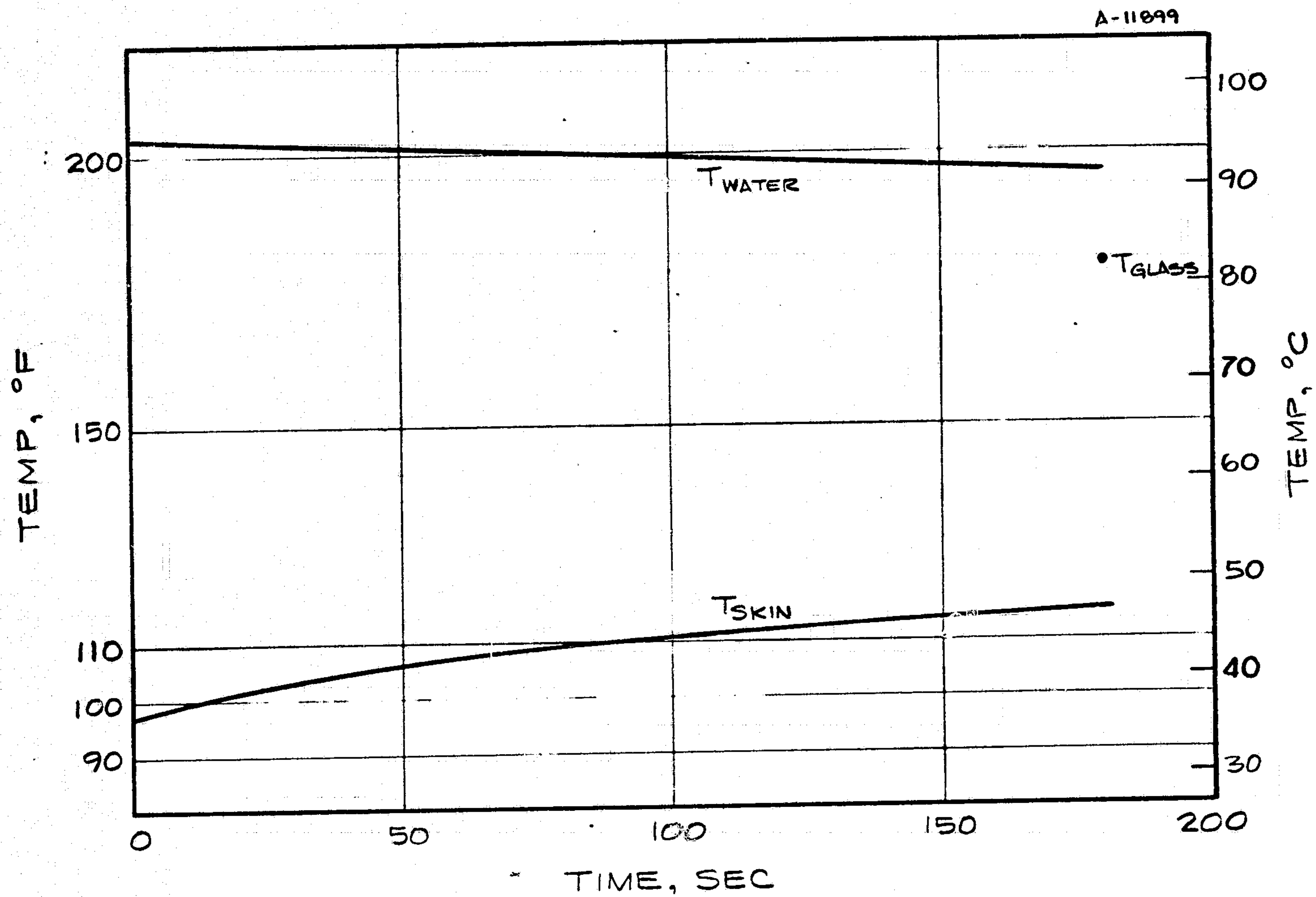



Figure 5-6. Skin temperature response of thumb (1st test), post-life test.

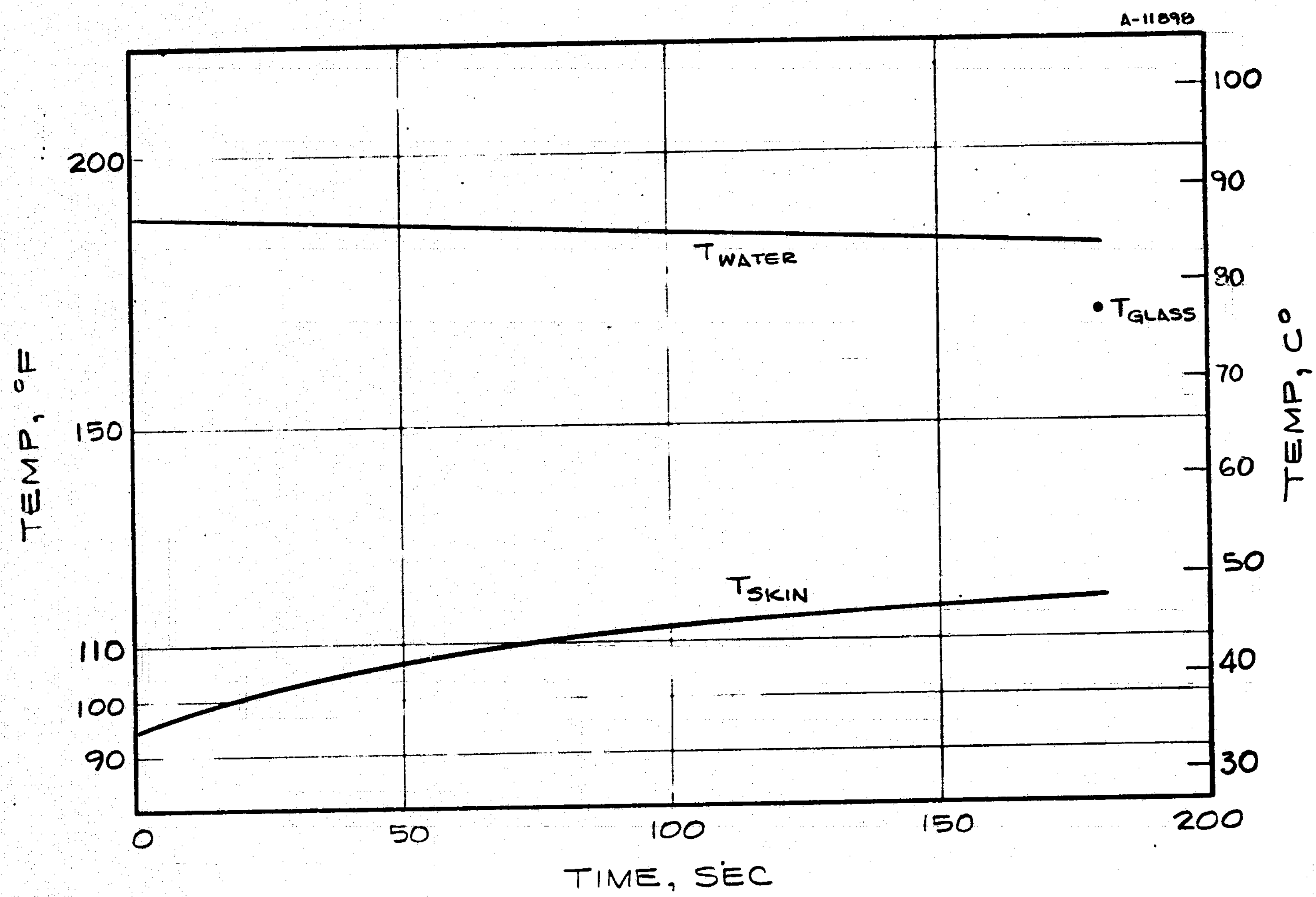



Figure 5-7. Skin temperature response of thumb (2nd test), post-life test.

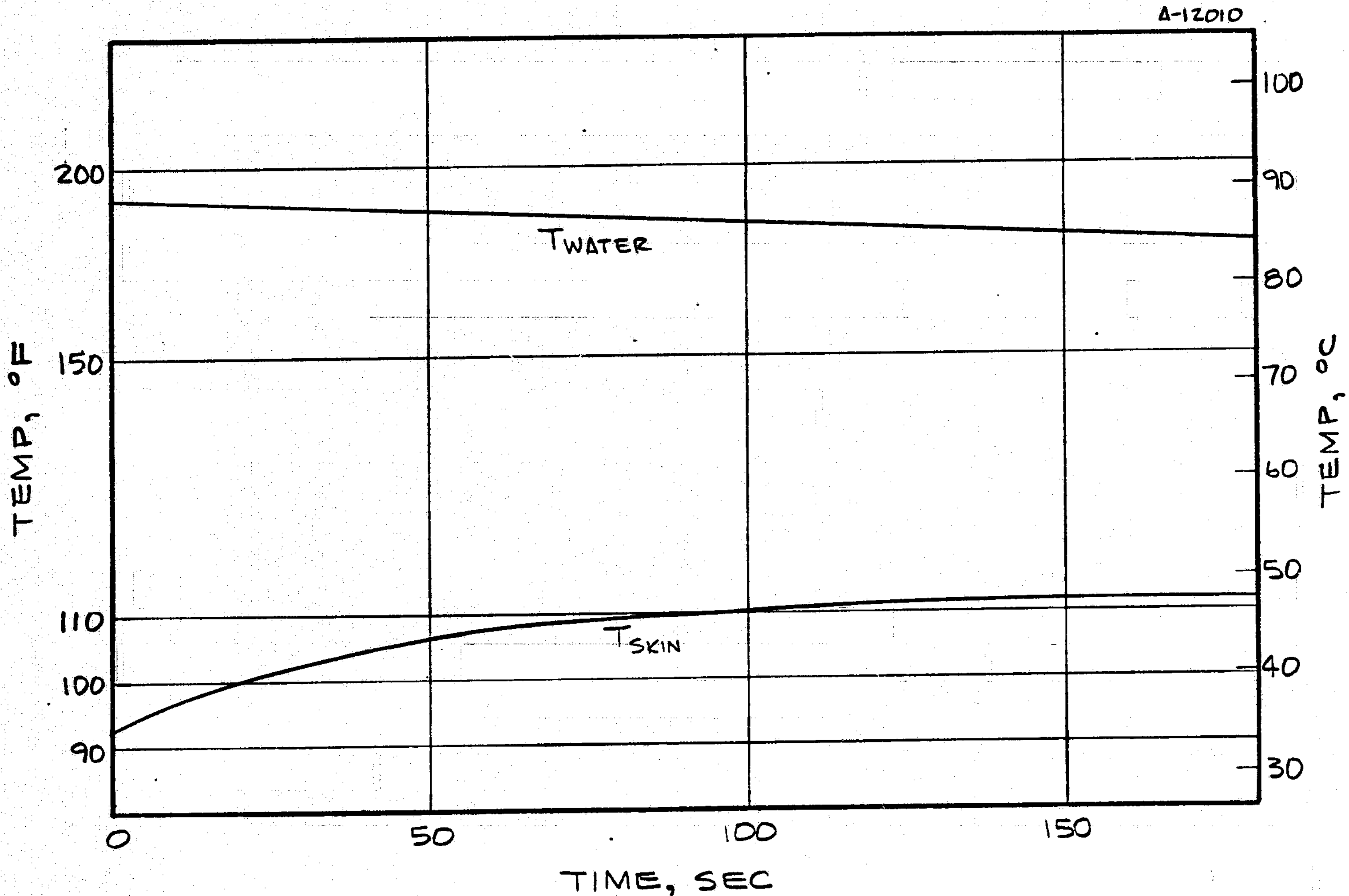



Figure 5-8. Skin temperature response of middle finger, post-life test.

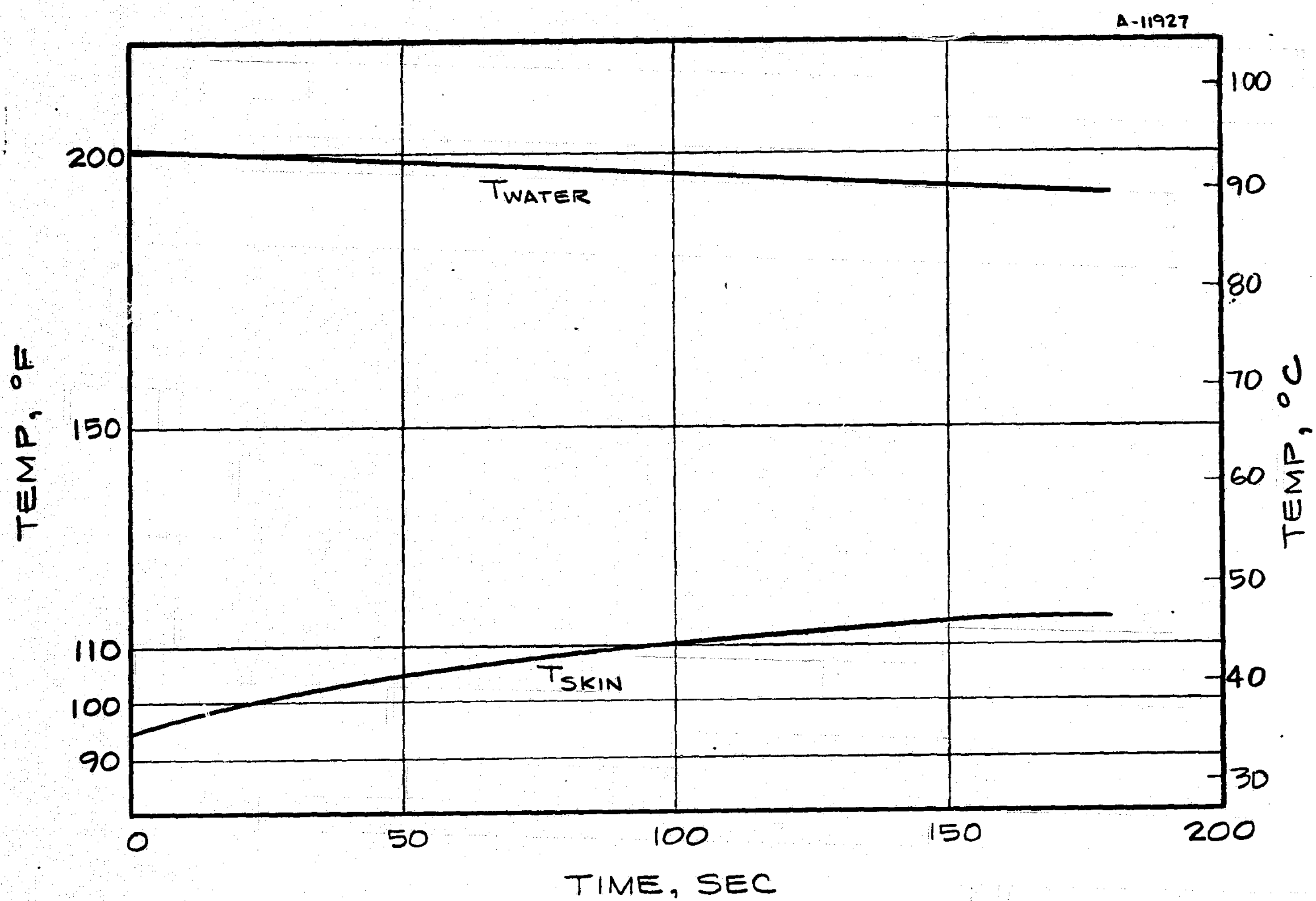



Figure 5-9. Skin temperature response of ring finger, post-life test.

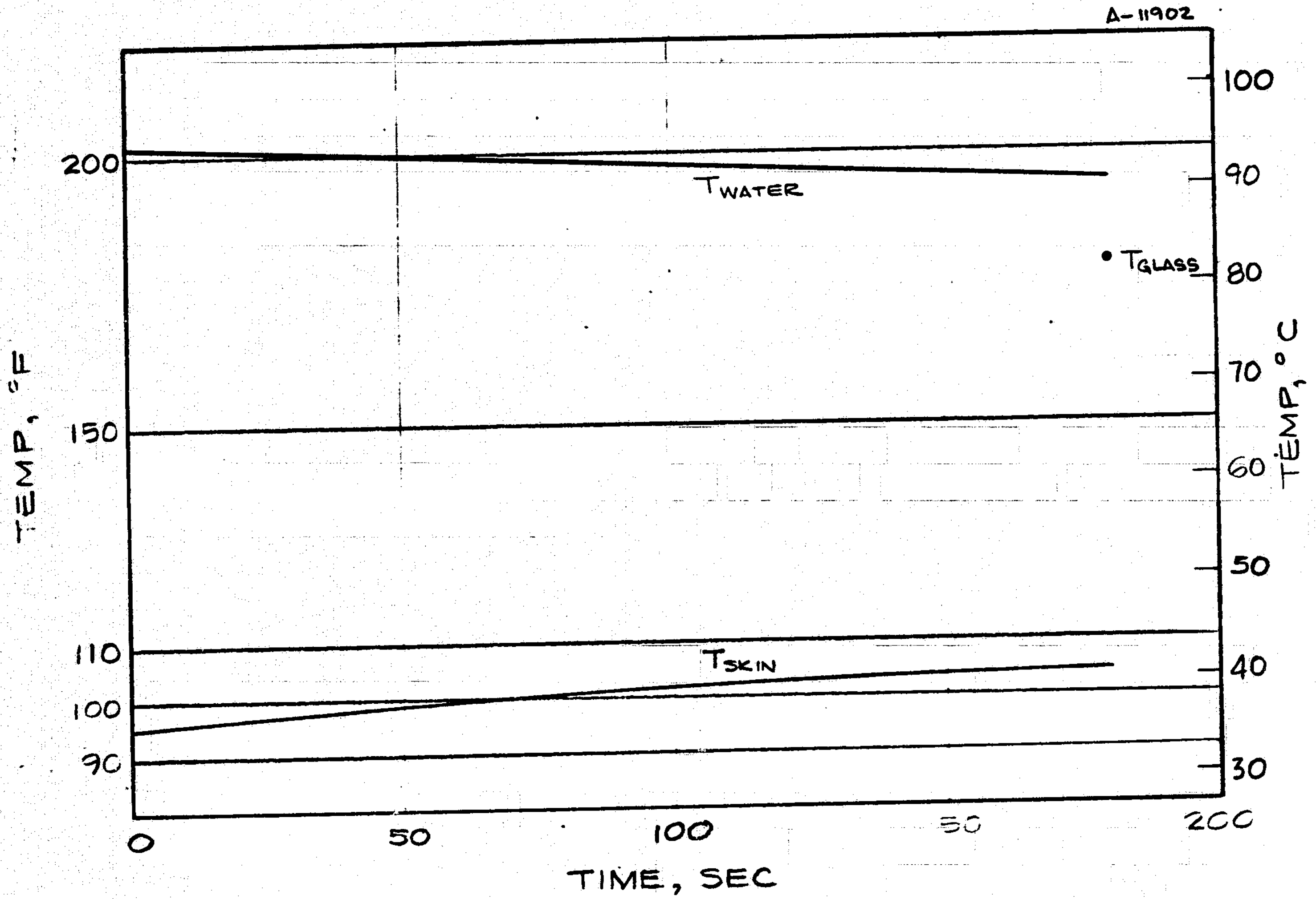



Figure 5-10. Skin temperature response of palm (under support bar), post-life.

problem. The variant response was attributed to the 5.5°C (10°F) temperature difference between the water temperatures. To confirm this hypothesis, a computer run was made using the post-life test data inputs, and this run predicted 43.3°C (110°F) temperature would occur at 55 seconds into the test using the appropriate one atmosphere conductivities for new felt.

Subjectively, the ring finger felt as if it has a "hot spot" at the tip of the finger Consequently, an unscheduled test was run to determine the actual temperature profile of that location. The results appear in Figure 5-9 and, although no pre-life test comparison was available, show a reasonable 90 seconds to failure for a high mean water temperature of 91.2°C (196°F). This corresponds well with the other test data and no evidence of failure was found on the insulator in this region upon inspection.

The palmar area again in the post-life test showed a flat response that did not exceed the 43.3°C (110°F) mark, although it did rise higher than the pre-life test curve. This is again attributed to the higher water temperatures maintained in the post-life testing.

The conclusion from the last two series of tests, inspection of the glove, and computer runs was that no significant degradation of the thermal insulating properties of the phase pressure-thermal glove combination occured as a consequence of the 100,000 manned life cycle test and that the glove satisfied the thermal design requirements.

## 5.2 THERMAL CONDUCTIVITY TESTS

Thermal conductivity tests were performed to ensure the adequacy of the data available for the thermal conductance of the felt layup at reduced pressures. Additionally, several samples were tested in an attempt to experimentally determine the advisability of including and aluminized layer in the thermal glove layup to reduce radiation transport through the felt.

The tests were conducted with a 10.1cm (4-inch) diameter samples using a guarded hot plate apparatus operated in a vacuum bell jar at a pressure of less than $10^{-5}$ torr. All the samples were constructed from the actual materials that were used in the construction of the Phase IA thermal gloves with the exception of the nonflammable ripstop material for which a neoprene coated ripstop of the flammable variety, but identical thickness, was substituted.

The heat flux through the sample was always from the Kevlar or Orthorfabric layer to the felt and ripstop layers which was maintained at approximately room temperature. Mean sample temperatures for the data points ranged for 37.8°C (100°F) to 126.7°C (260°F) with the maximum outside temperature reached generally being around 176.7°C (350°F).

Because the accuracy of a particular measurement was strongly a function of the change in temperature across the sample from the hot to the cold side data points calculated for mean temperatures below 37.8°C (100°F) were discarded. This left from three to four data points remaining from which a straight line curve fit was made covering the temperature ranges of interest. It is these plots that appear in the following figures.

Because of the weight of the cooling plates the samples were under a light compressure load throughout the test this was calculated to be slightly greater than 3400 $N/m^2$ (0.5 psi) and when comparing this to the previously available felt data. This should be taken into account. Figure 3-8 shows the relationship between conductance and structural loading for felts of this variety and approximate density. Because this value was determined at $N/m^2$ (0.5 psi) load and the grip surface worst case design condition is for a 34000 $N/m^2$ (5 psi) lead. Figure 3-7 must be used to determine a multiplying factor that represents the degree of degradation of the insulator in terms of increased heat flux.

From the 3400 $N/m^2$ (0.5 psi) condition to the 34000 $N/m^2$ (5.0 psi) point represents a change in the thermal conductivity of 187 percent. Multiplying the experimentally derived value by this results in a layup conductance of 1.05 Btu/ft$^2$-hr°F. The design goal for the grip area at 93.3°C under compression was established (Figure 3-7) as being 1.84 Watts/m$^2$°C (1.05 But/ft$^2$-hr°F)which was exceeded by the phase IA glove construction.

The cases for the gauntlet layup and the three layer MLI also showed a satisfactory degree of protection in the experimentally tested layup and meet or exceed the conductance design goals established early in the program.

The second testing series was directed at determining improvement that could be made to increase the effectiveness of the layup or simplify construction techniques.

First, the effect of an aluminized radiation shield was investigated as a means of reducing the thickness of felt by increasing its effectiveness. Four samples were run and the results with a description of the layup cross-sections are given in Figure 3-10. For comparison with these the same samples without the aluminized layer is shown on the same plot. In general, an increase in the effectiveness of the layup of from 20 to 30 percent was achieved by reducing radiation transfer

The sample denoted as aluminized Orthofabric was an experimental sample on which a low emissivity transfer film of aluminum was applied by the 3M company identical to the type used for heat reflectance on fireman's turnout coats. This did not perform as well

as the layer of aluminized mylar but did show a significant improvement over the sample with no radiation barrier and would be considerably simpler to fabricate.

One final test was conducted to examine the feasibility of having a loop "fuzz" of Nomex fiber woven into Orthofabric as it is currently done with Velcro fastener material. This would then be a one fabric insulator combining the Orthofabric and the substrate insulator standoff is one material. No such woven material is currently available and so it was simulated with a sheet assembled from Velcro loop side material and the results of this test and the plot of the current Orthofabric felt layup are shown in Figure 7-2. The results, although roughly 15 percent higher in conductance than the phase IA gauntlet layup, are felt to be quite promising. With a fiber stiffness and density optimized for insulation one layer of this material could probably be brought to virtual equivalence with multiple layers system used in the program considerably while retaining the merits of good optical, insulation, and abrations properties.

The conclusion of the thermal conductivity testing was that the Phase IA insulators demonstrated conductances in $10^{-5}$ torr environment that met or exceeded the design goals, that an aluminized radiation shield could significantly increase the effectiveness of the felt type insulator layup and that several promising techniques can be employed to simplify construction without degrading the design performance or increasing existing insulation thicknesses.

## 5.3 LIFE TESTS

The 100,000 man cycles were performed on Glove I to insure that the combination pressure glove/thermal glove can perform the cycling requirements without measureable deterioration.

The tests were performed in a glove box pumped down to and controlled at -4 psig. The box contained two miscro switches and associated electronics and counter within it as shown in Figure 5-11.

The relays are interlocked so that one must be tripped before the other one can be excited. This setup prevents the test subject from multiple hitting one switch, and forces each switch to be hit alternately before a pulse registers on the counter. One microswitch was positioned such that it is touched with the dorsal side of the phalanges with the palm fully open (see Figure 5-11 for clarification). The second switch was positioned in the frontal portion of the box so that it had to be touched with the knuckles with the first closed and after a full rotation of the wrist. The purpose of the barrier was to force the test subject to close his fist in order to clear the barrier.

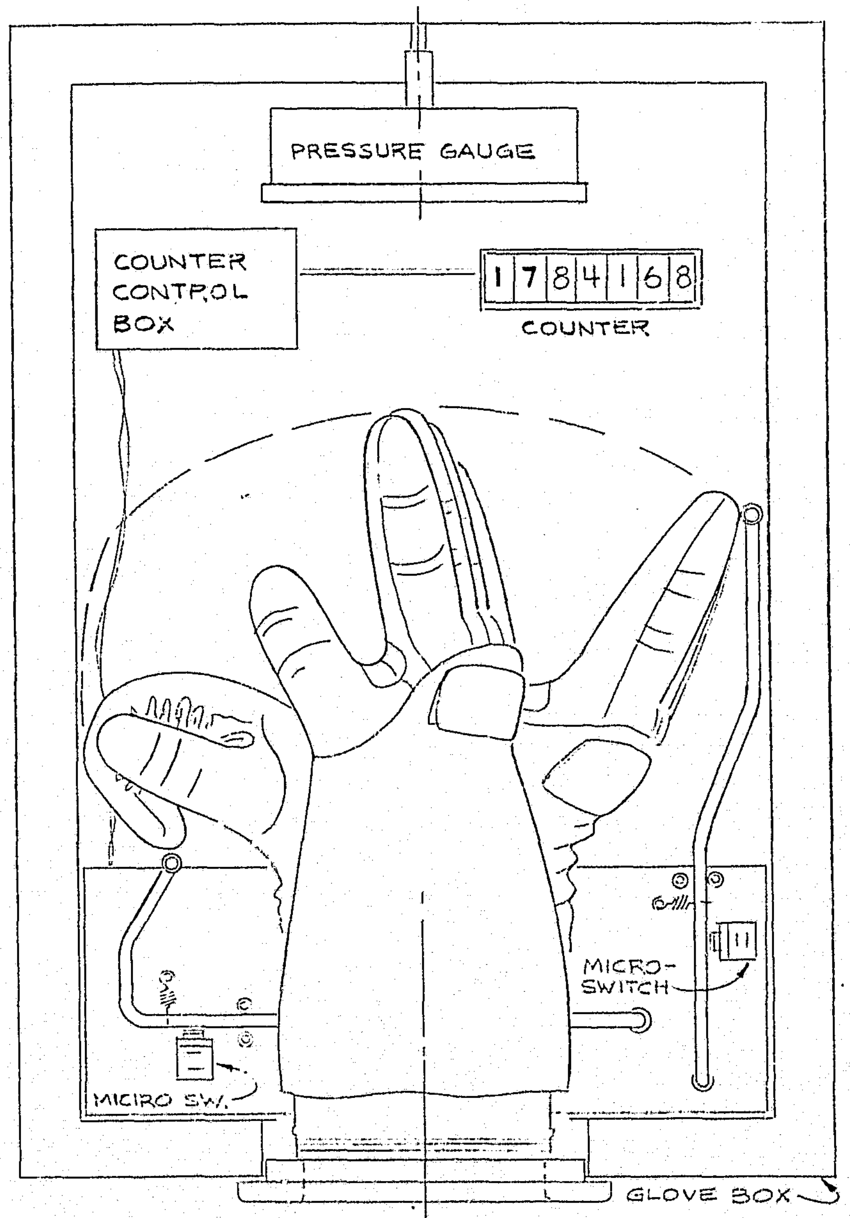



Figure 5-11. Top view of glove box showing experimental set-up for 100,000 cycle life tests.

The test subject doned a comfort liner and placed his hand into the glove and began cycling. The counter was pulsed as each microswitch was hit in turn; two pulses were required to count one.

The glove was cycled at a rate of 20 to 30 cycles per minute. Two test subjects involved with the testing alternated positions every 200 cycles.

The only modification made to the thermal glove took place at 36,000 cycles. This modification dealt with the relocation of the Velcro fasteners along the knuckles to a position further back as they were pulling free from their original location. This slippage had exposed the Velcro bristles to the pressure glove and some abrasion of the Kevlar was observed. Although this corresponded with the time the leak rate stabilized no leadage was caused by the abrasion and the two events were unrelated. The leaks in the glove that developed in the pressure bladder was predominately situated under the seams of the fingers and where ever the Kevlar restraint layer was creased in the cycling motion.

Problems that developed with the thermal glove during the life test all appeared by the first 20,000 cycles and were primary concerned with the coatings on the thermal glove wearing off with the exception of the Velcro problem in the finger at attachments already mentioned.

The silicone RTV high friction coating did not adequately bond to the Kevlar of the grip surfaces and as a result blistered and pealed throughout the test. This difficulty was corrected and life tested 100,000 cycles under a different NASA contract and the solution of using a modified surface preparation and application procedure worked most satisfactorily. The improved coating process was used on the Phase IA glove.

The nonflamable neoprene coating on the ripstop inner layer of the thermal glove also began to wear, but not to the extent that its function as a pressure barrier would be compromised. This same problem also occured with the blue neoprene at 86,000 cycles indicating that even commerically applied coating would wear in time.

The only evidence of wear in the pressure glove, besides the increased leak rates, was the Kevlar restraint cords of the lower wrist joint which showed signs of fraying after 40,000 cycle. This caused the test program to be modified slightly by the addition of a 6 psig structural check that was performed every 10,000 cyles thereafter for safety reasons. The last check occured at 90,000 cycles and no evidence of structural failure was noted at that time.

Test subjects reported that no undue discomfort was associated with the thermal glove. Subjects reported pressure points near the base of the thumb. These same pressure points existed with the pressure glove alone and are not associated with the thermal glove.

Conclusions of the life test were that the Velcro tabs securing the thermal glove to the pressure glove needed to be repositioned and supplemented and that the RTV coating adhesion to the Kevlar had to be improved. Both of the modifications were implemented in the final pair of Phase IA thermal gloves. Additionally, future consideration might be given to improve bonding of the neoprene to the inner layer of the thermal glove although functionally the current arrangement is satifactory. No problems were observed with strength of the seams although the fabric itself did expand and resulted in a looser fit. A tighter fabric development was employed on the final gloves to compensate for this phenomena.

## 5.4 LEAK RATE

Leak rates for the pressure gloves were measured at intervals of 20,000 cycles during the life tests and the results are plotted in Figure 5-12. The leak rate climbed steadily during the first third of the test beginning from the initial rate of 15 scc/min and climbing to about 25 scc/min. The leak rate recorded at 60,000 cycles was undoubtedly an error owing to a leak somewhere in the leak check system.



## 5.5 MOBILITY TESTING

Testing was performed on the Phase I pressure glove and pressure/thermal glove combination to determine the degradation in mobility caused by the addition of the thermal overglove. These tests were conducted prior to and upon completion of the 100,000 cycles manned life test and also served to document any change in the mobility of the gloves as a result of cycling. Bending forces were measured for flexion and extension of the fingers and wrist as well as adduction and abduction of the wrist. The center of movement was then determined and the bending moment in units of gram-centimeters calculated.

The data was reduced from a series of photographs that were taken as the fingers or wrist was bent with a spring scale held nearly perpendicular to the glove member. A reference grid was provided behind the glove to ease measurements of angular deflections. Each photograph then yielded a data point consisting of angular deflection, a bending force and a moment arm from which a deflection vs moment diagram could be developed.

The stable range was defined by two photographs in which the member was first bent to one direction and allowed to come to rest and then bent in the opposite direction and allowed to return. The center of this angular range was defined as the zero degree position on the moment-deflection graphs. Because of differences in the rest position of the pressure and thermal gloves the zero degree point does not correspond to exactly the same position on

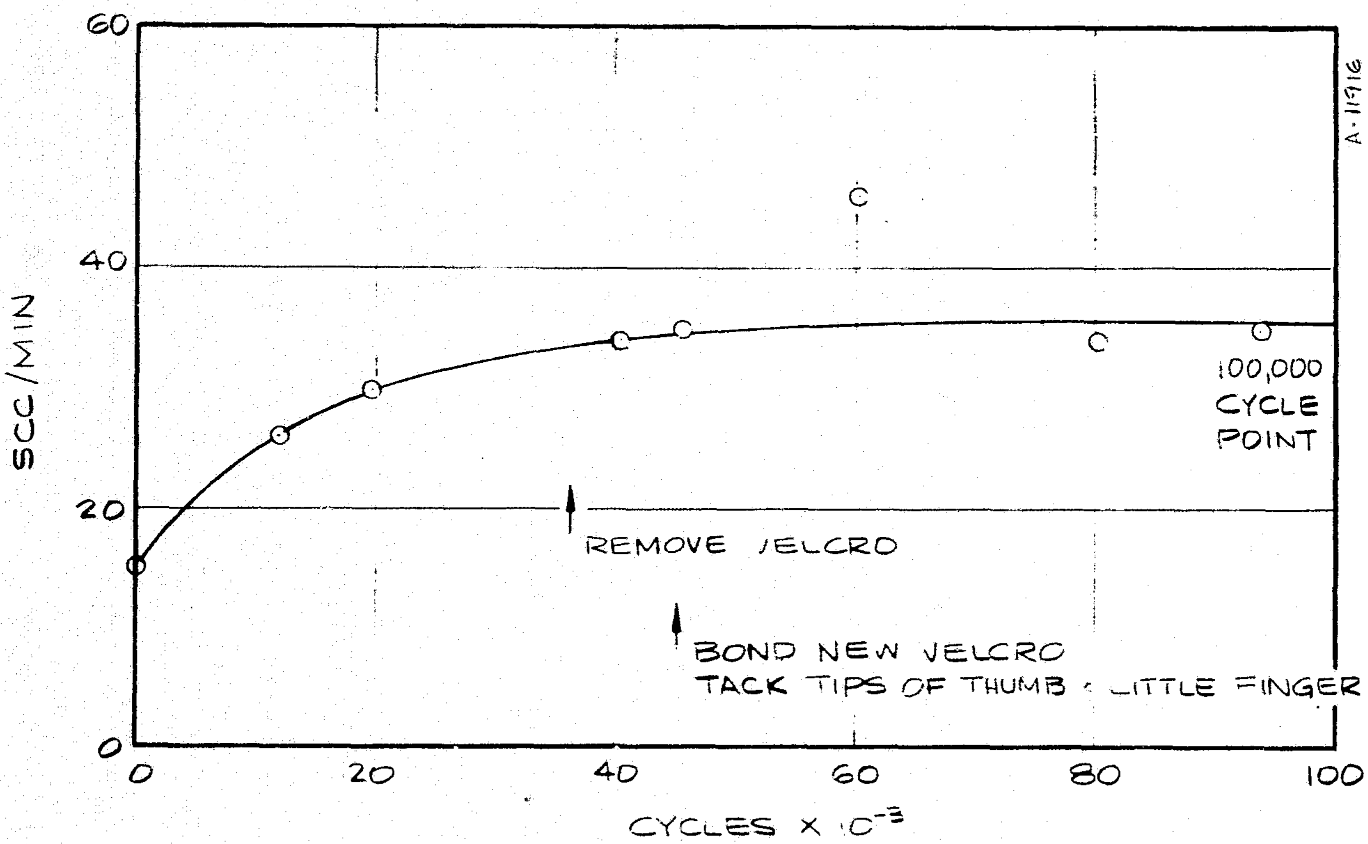



Figure 5-12. Leak rate of phase I pressure glove during 100,000 cycle manned life-test.

the pressure glove as it does on the pressure thermal glove combination. Consequently, when interested in the moment necessary to reach the open hand or clenched fist positions, it is best to compare end points on the graphs regardles of angular displacement. For a measure of the "efficiency" of movement to a given displacement it is accurate to compare moments to reach corresponding identical angular displacements. Both measures are of value although the moment to reach a clenched fist is undoubtedly the most important to the working astronaut. These comments do not apply of course to the wrist joint because the rest positions of the thermal and pressure glove coincided on both axes of movement.

These diagrams for the various glove fingers and the wrist joint appear in Figures 5-13 through 5-26 for the pressure and pressure/thermal gloves. For ease of comparison both the prelife test and post-life test data are plotted concurrently on the same graph and the corresponding baseline pressure glove data appears in the adjacent figure. Figures 5-13 and 5-14 show the results of the thumb testing. The effect of the additional of the thermal glove is to increase the stable range of the finger from 18° to 34°, probably as a result of the additional stiffness in the thermal glove which inhibits the return of the pressure glove to its narrower stable range end points. For flexion of the thumb, no significant change in bending moment occured, and for extension, the torques were decreased. This was due to the fact that the Phase I thermal over-glove had a rest position with its fingers open in contrast to the pressure glove which had clenched fingers when at rest.

The observation made here is that, through serendipitious events, the thermal glove was designed with counteracting moments from the pressure glove. The net effect was to broaden the zero moment operating range and reduce the total moments. This did not occur on other fingers.

The next pair of graphs (Figure 5-15 and 5-16) for-the index finger illustrate no change in the stable range ($\sim$34°) but show an increasing slope to the moment curves as a result of the addition of the thermal glove. For a flexure of 60° this represents an increase from 1100 gm-cm (0.08 ft-lbs) to 1400 gm-cm (0.10 ft-lbs) or a 27 percent change. In extension, the range of movement was reduced from 50° to 20° and the resultant full deflection moment went from 2200 gm-cm (0.159 ft-lbs) to 2800 gm-cm (0.202 ft-lbs).

Figures 5-17 and 5-18 present the data from the middle finger. The stable range was improved from 40° to 48° but the flexure moment to reach 60° of deflection increased 97 percent from 810 gm-cm (0.059 ft-lbs) to 1600 gm-cm (0.116 ft-lbs). Forces to fully extend the finger veritcally increased 29 percent and an increase of 50 percent occured to reach a closed fist.

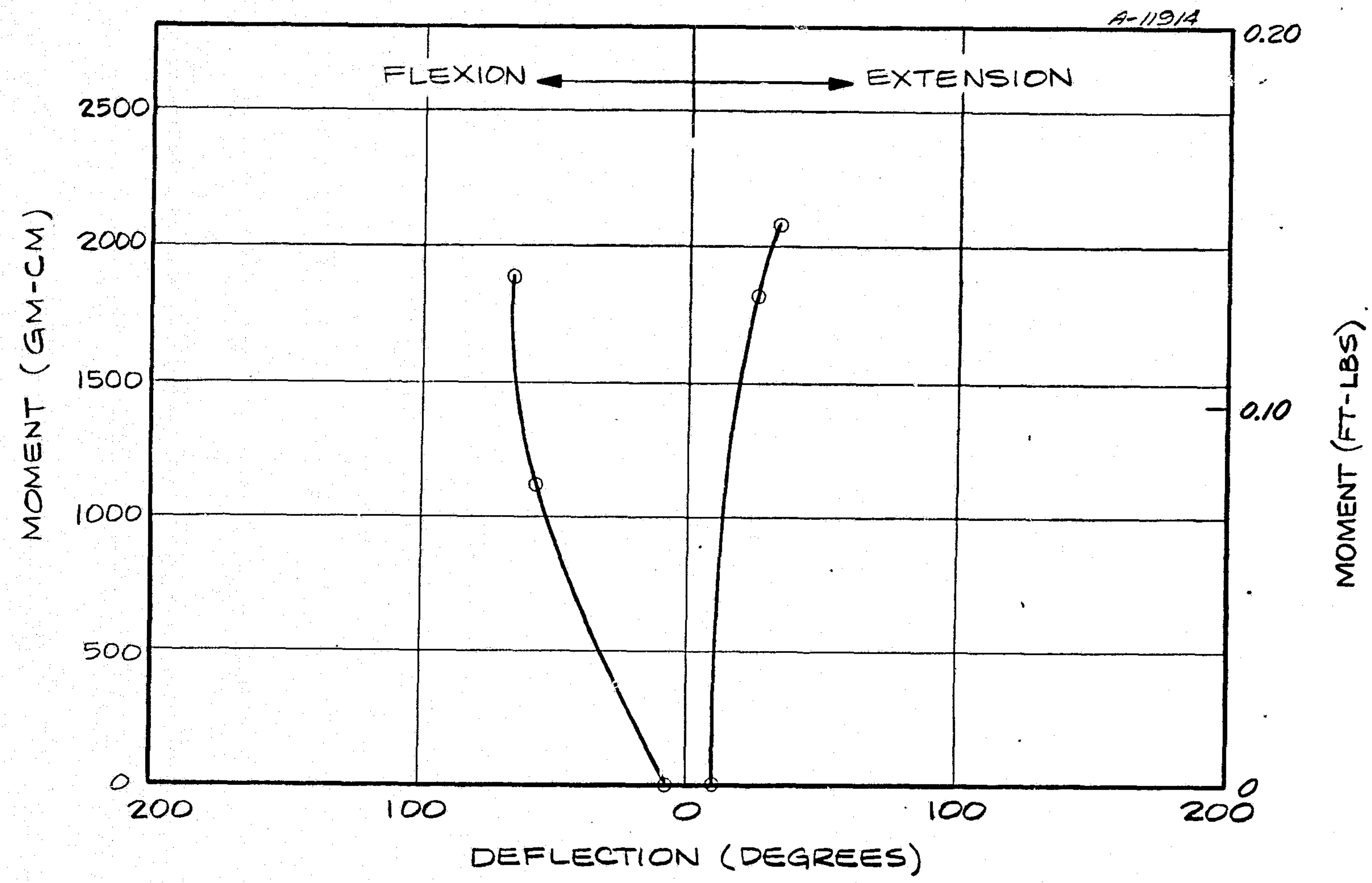



Figure 5-13. Mobility test of baseline pressure glove thumb.

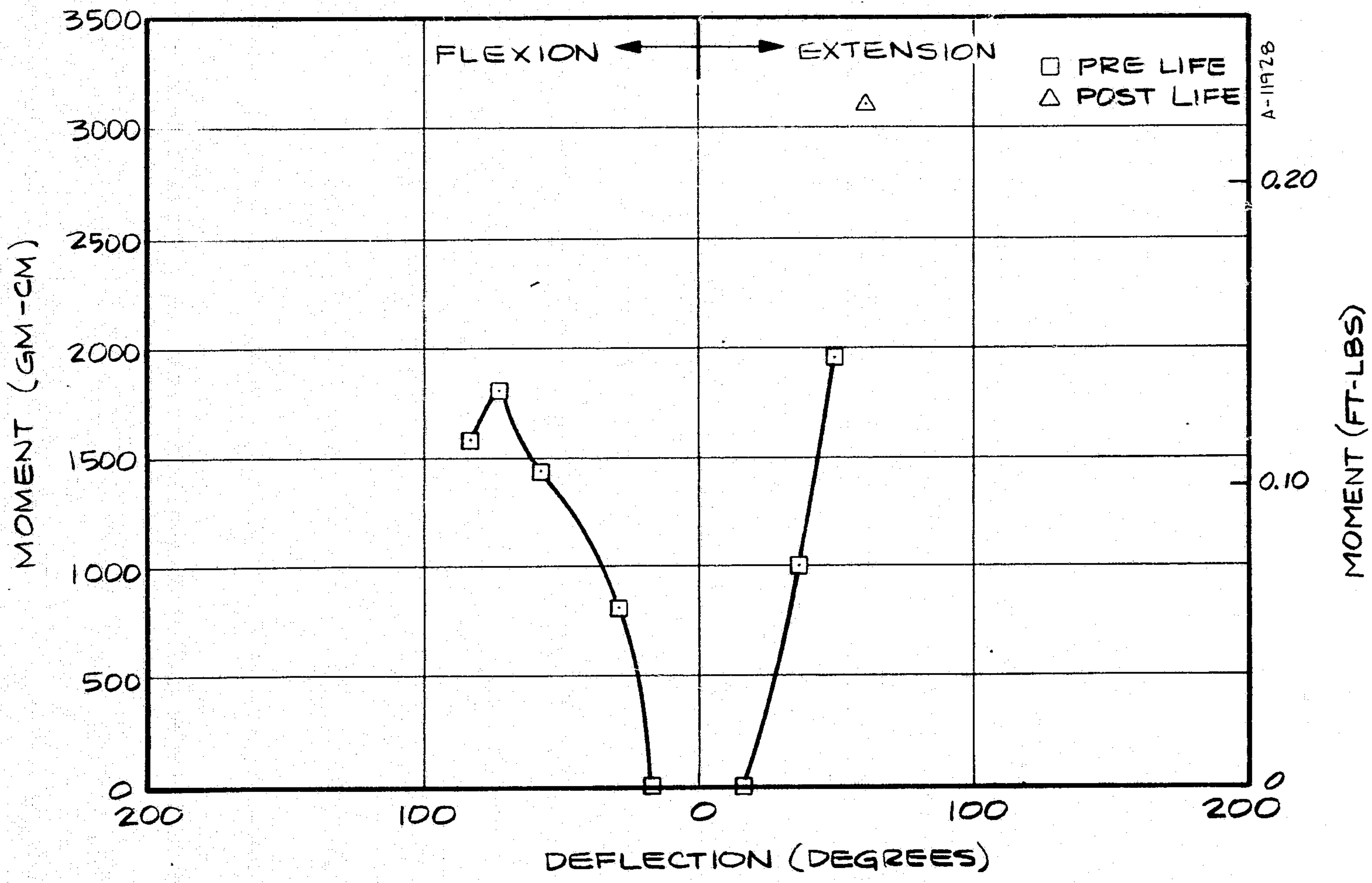



Figure 5-14. Mobility test of thermal/pressure glove thumb.

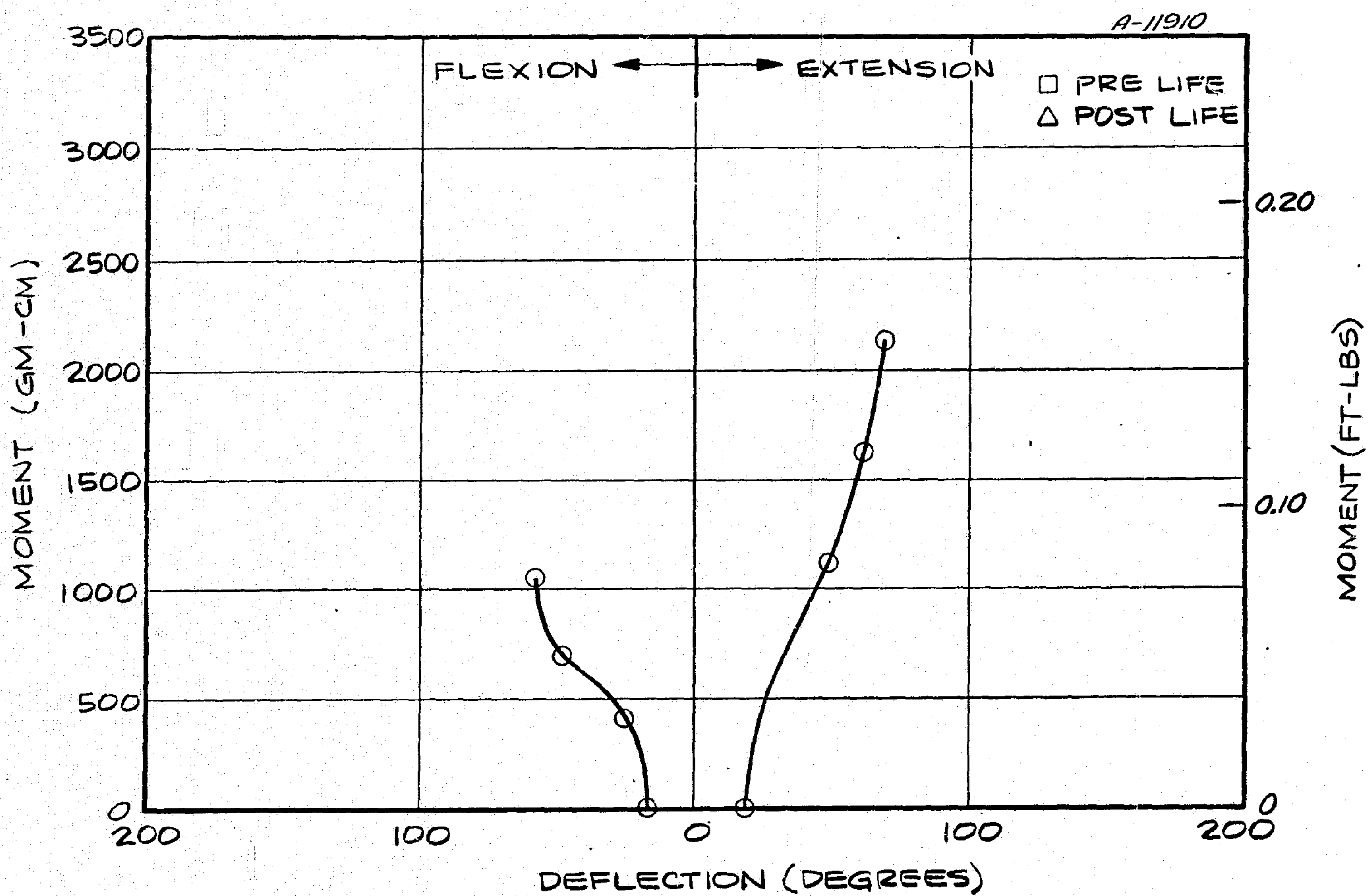



Figure 5-15. Mobility test of baseline pressure glove index finger.

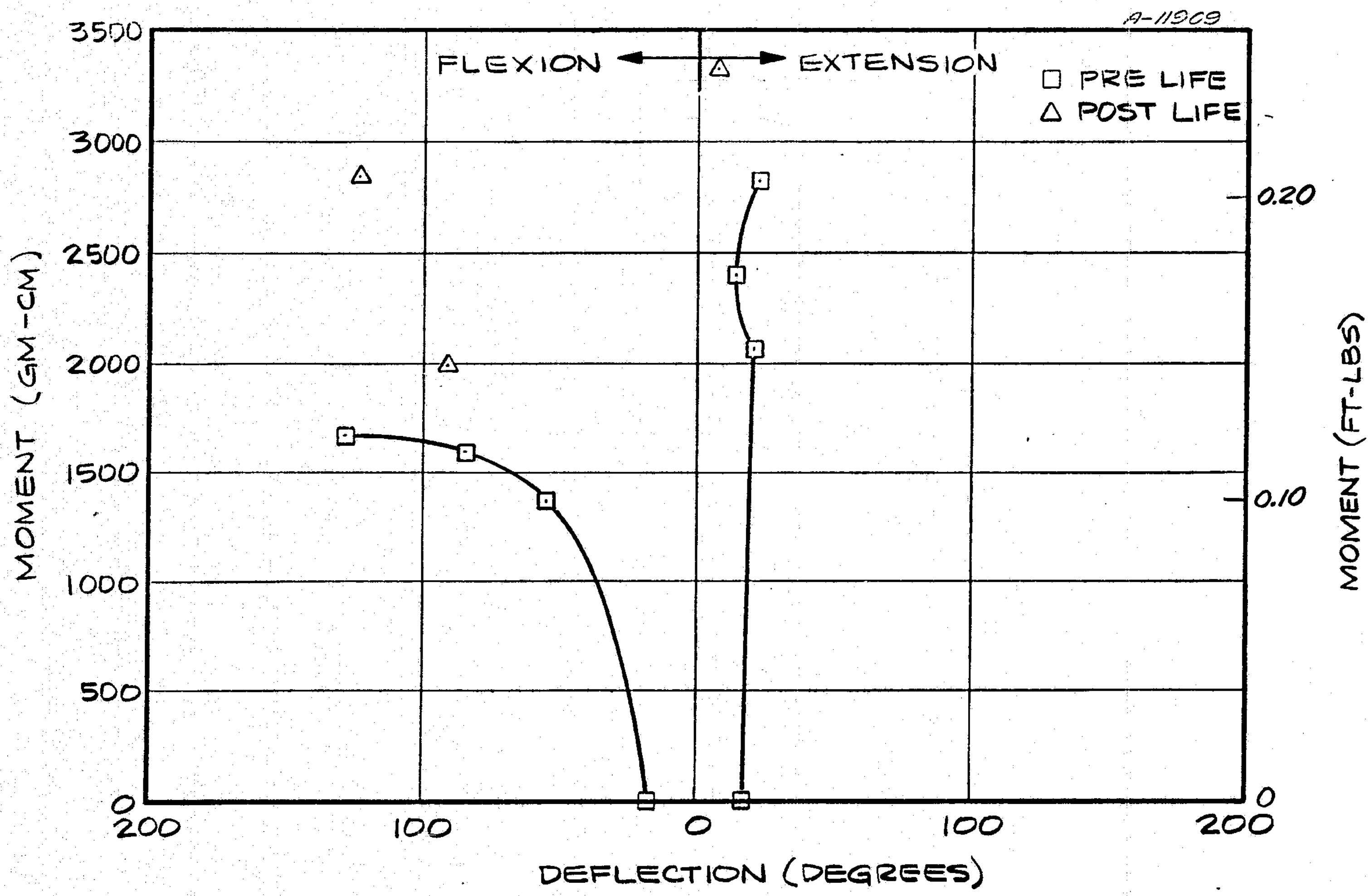



Figure 5-16. Mobility test of thermal/pressure glove index finger.

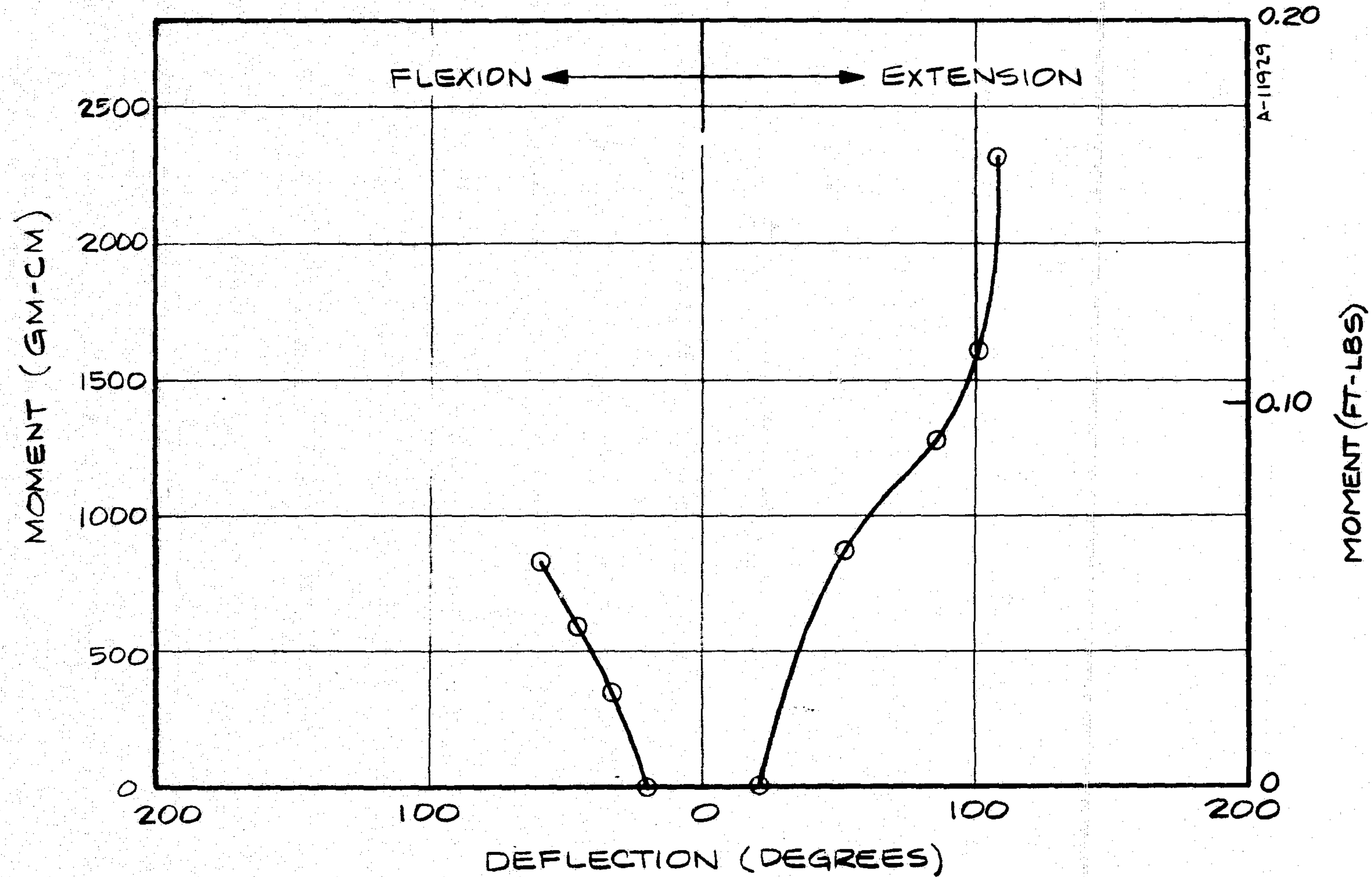



Figure 5-17. Mobility test of baseline pressure glove middle finger.

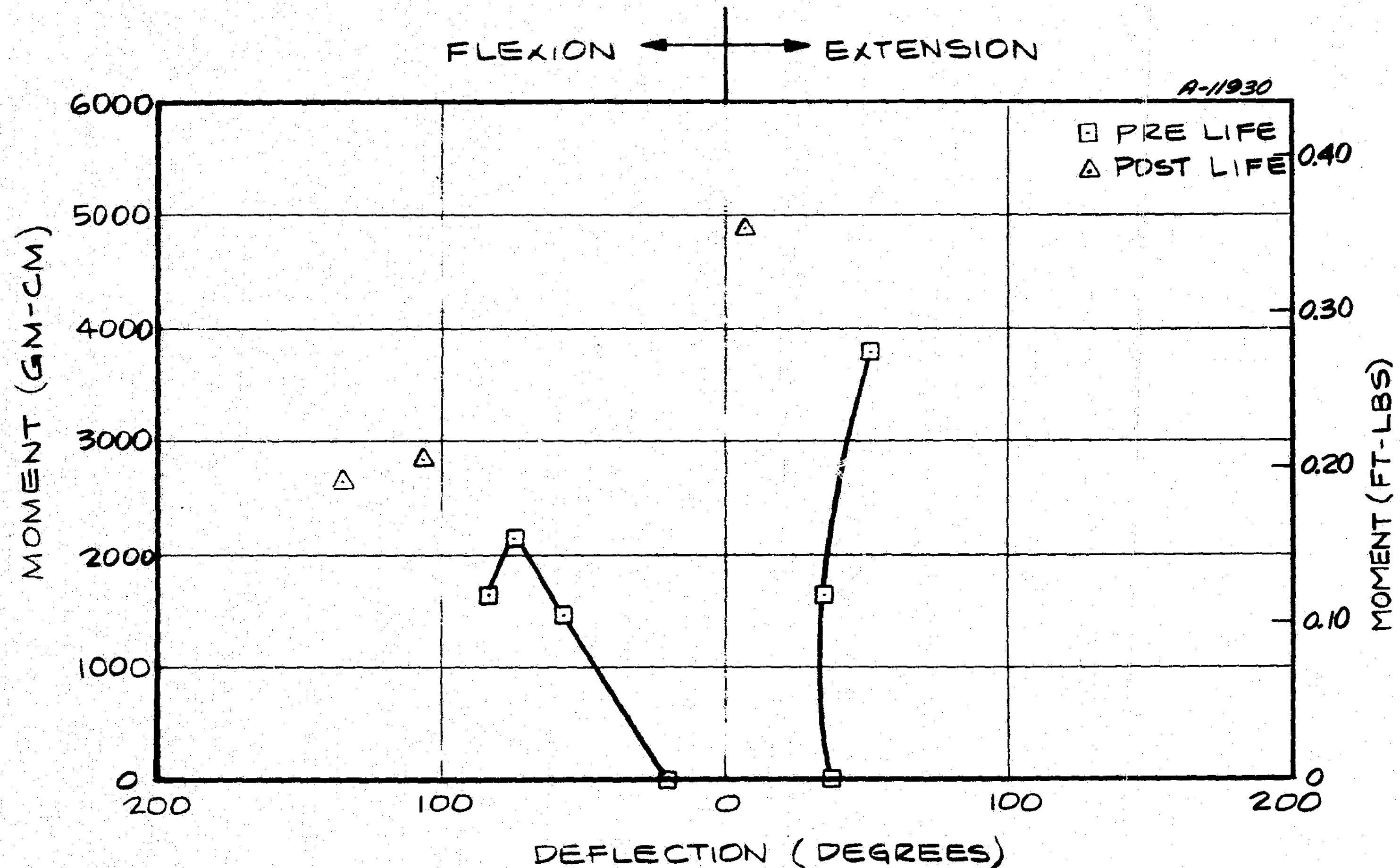



Figure 5-18. Mobility test of thermal/pressure glove middle finger.

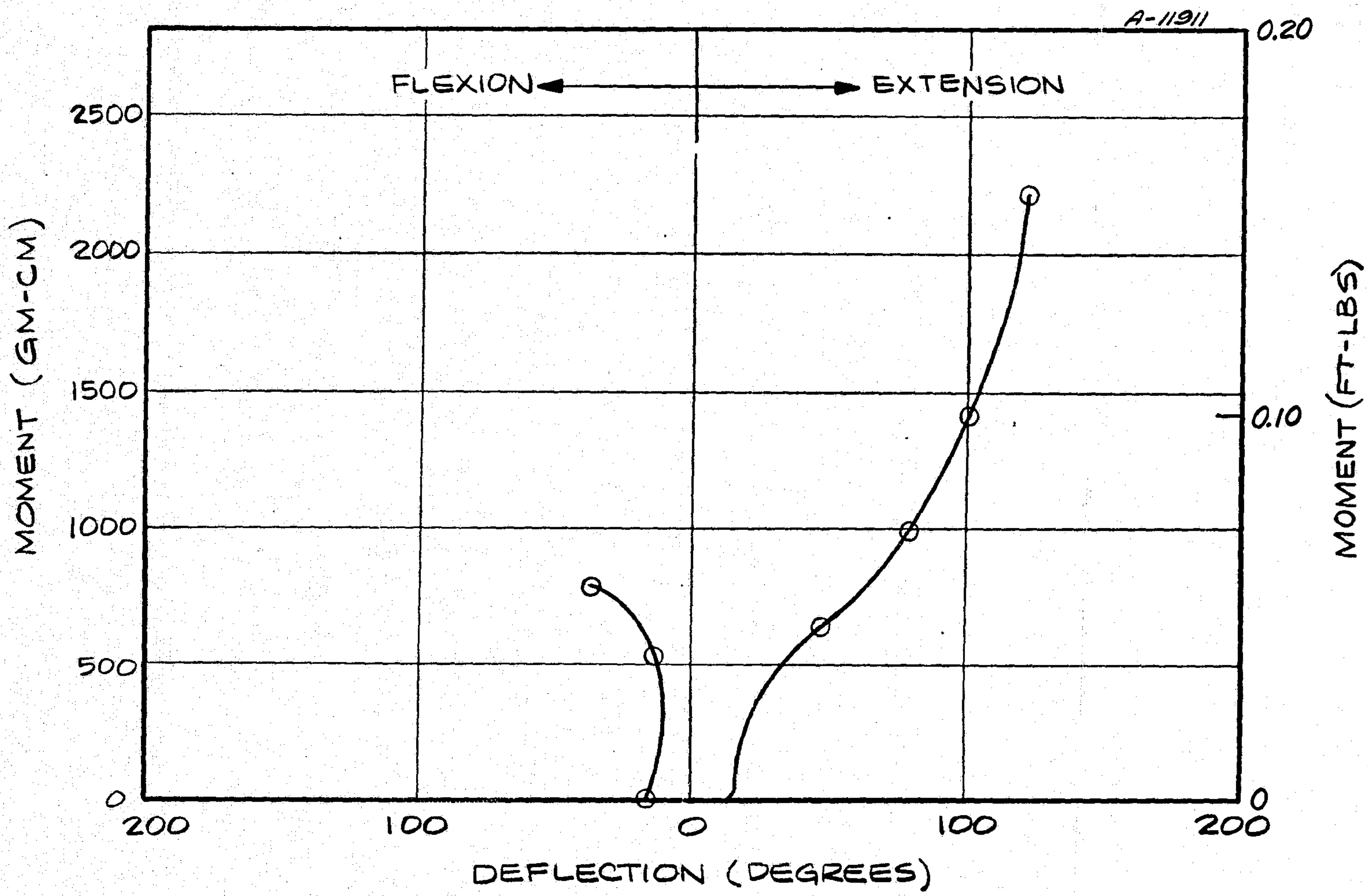



Figure 5-19. Mobility test of baseline pressure glove ring finger.

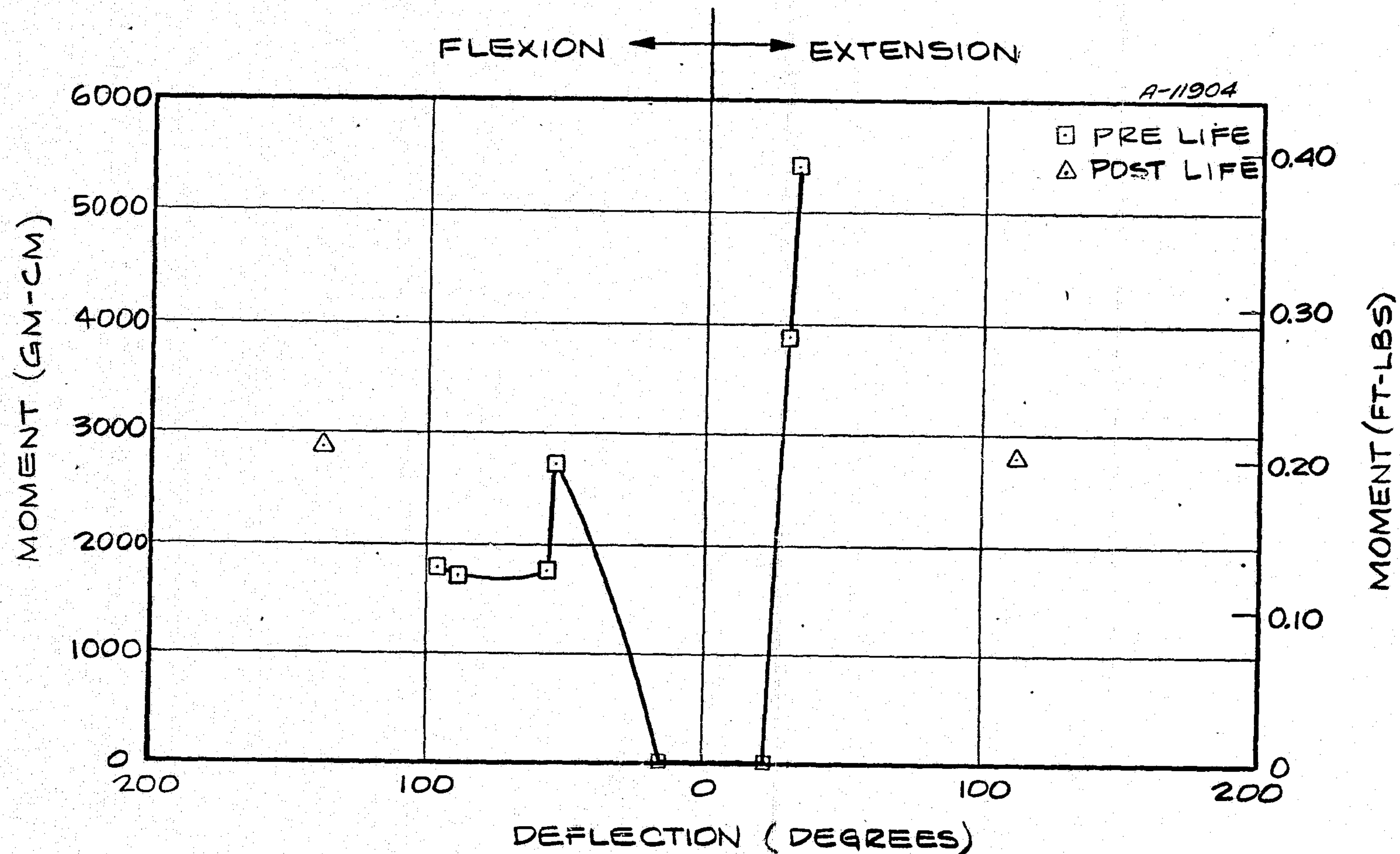



Figure 5-20. Mobility test of thermal/pressure glove ring finger.

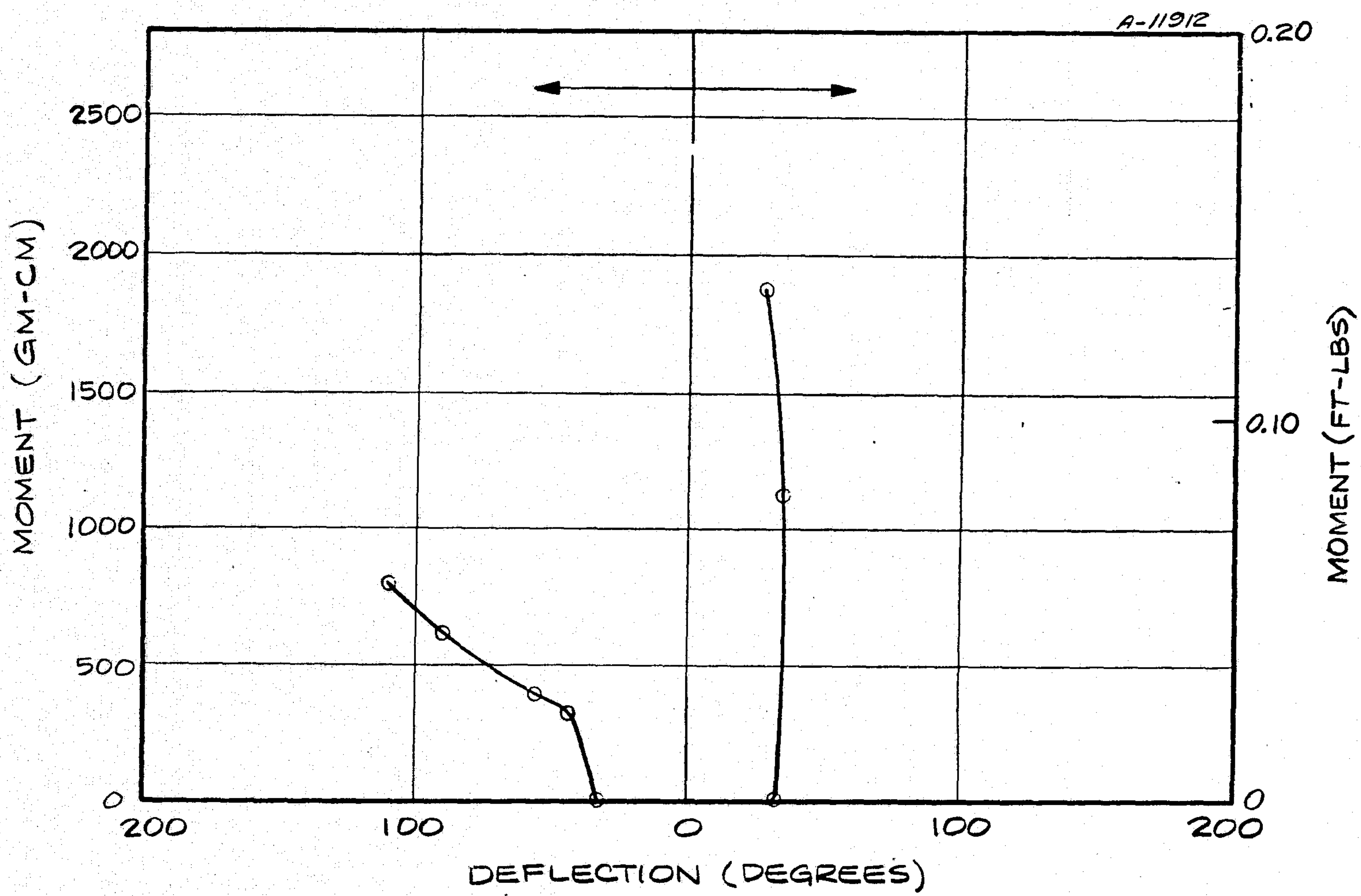



Figure 5-21. Mobility test of baseline pressure glove little finger.

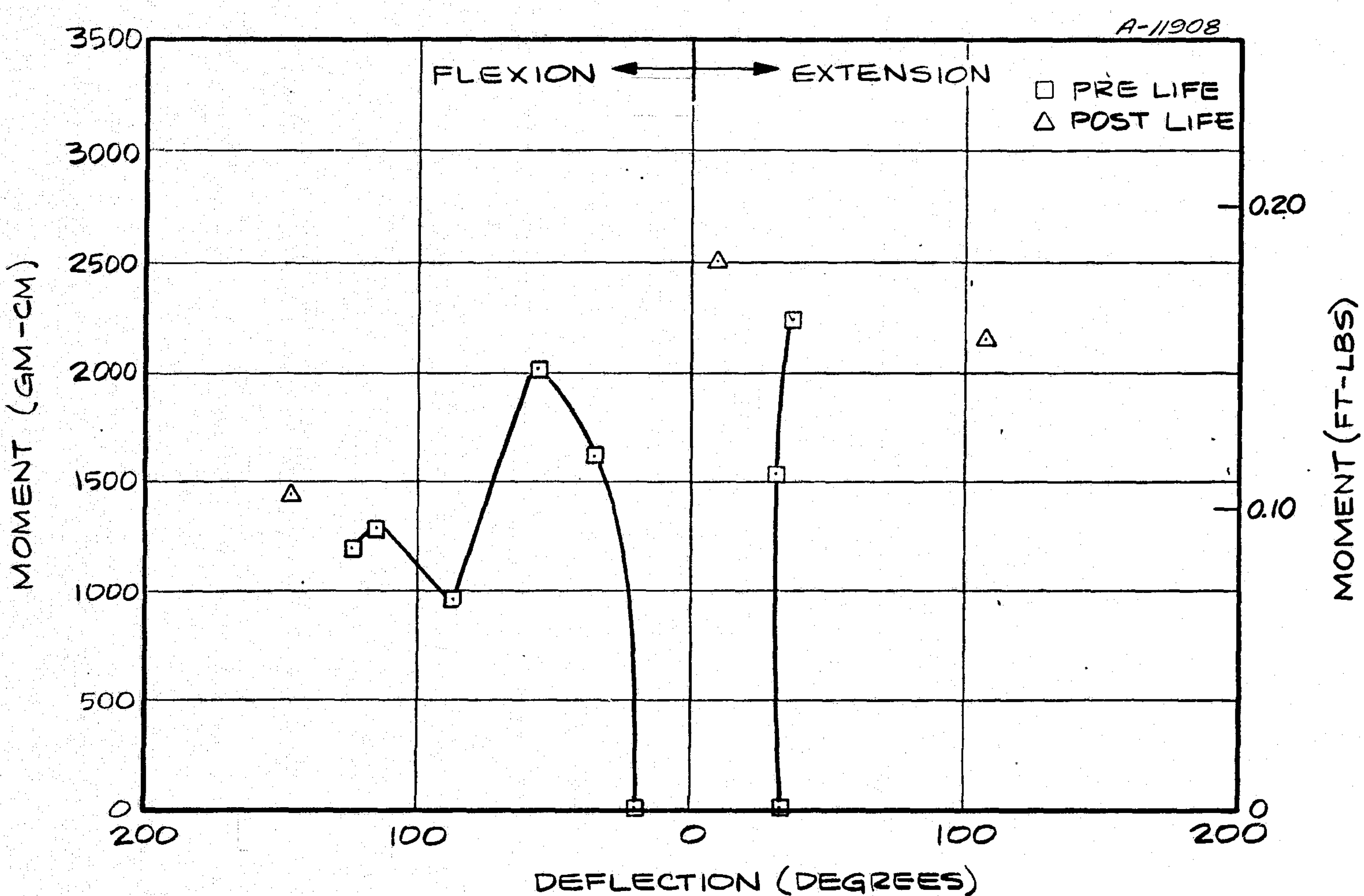



Figure 5-22. Mobility test of thermal/pressure glove little finger.

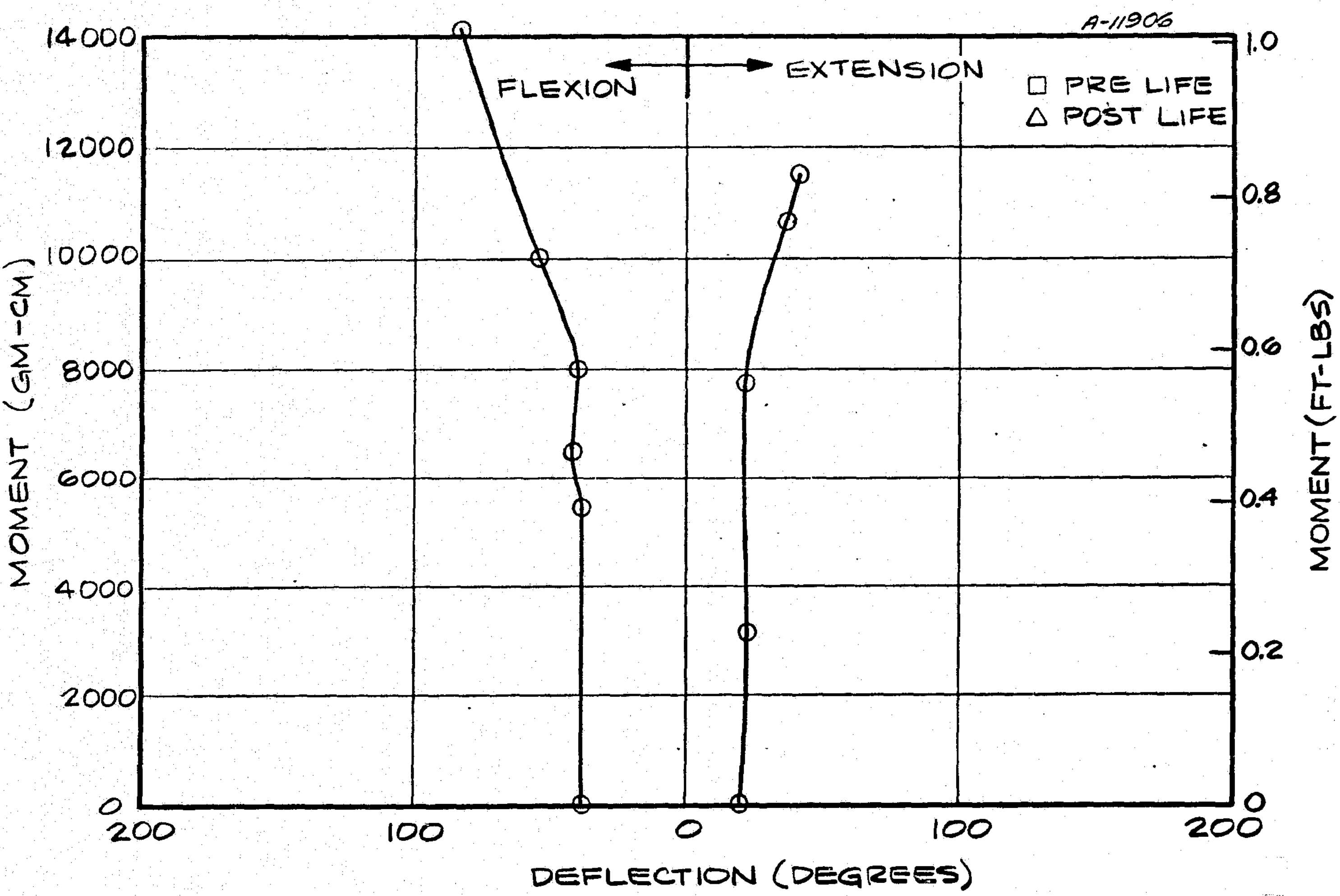



Figure 5-23. Mobility test of baseline pressure glove wrist.

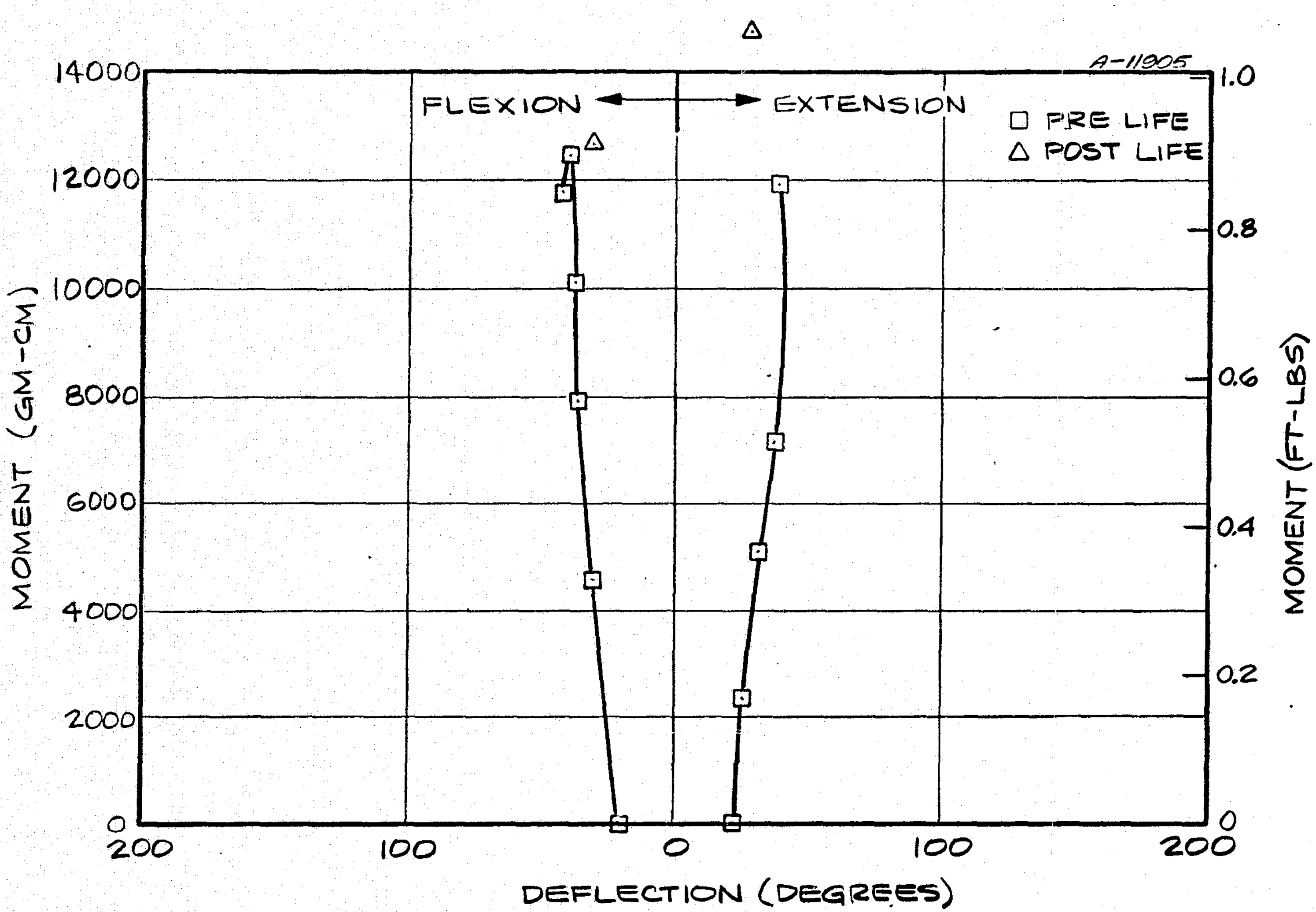



Figure 5-24. Mobility test of thermal/pressure glove wrist.

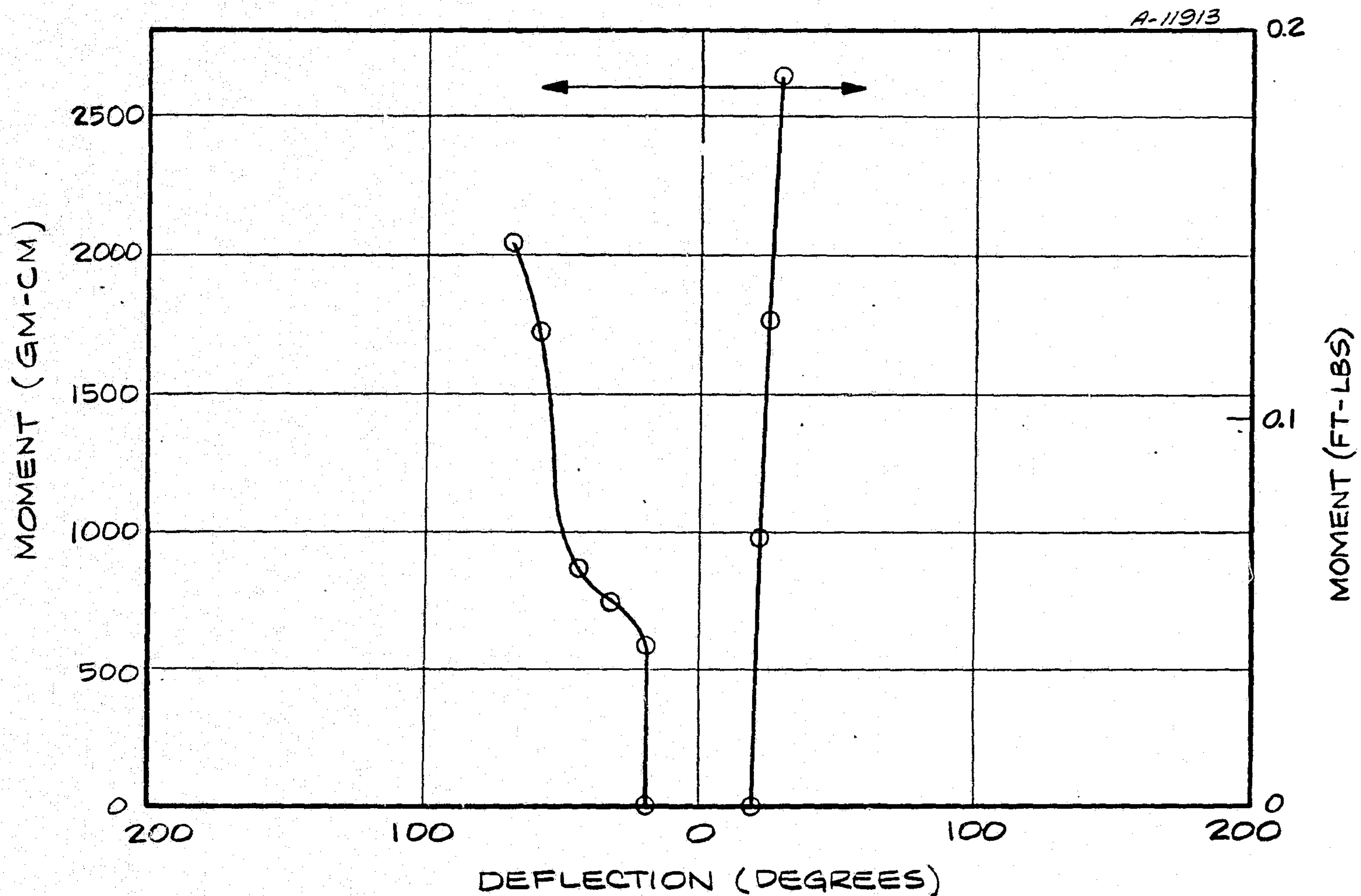



Figure 2-25. Mobility test of baseline pressure glove wrist.

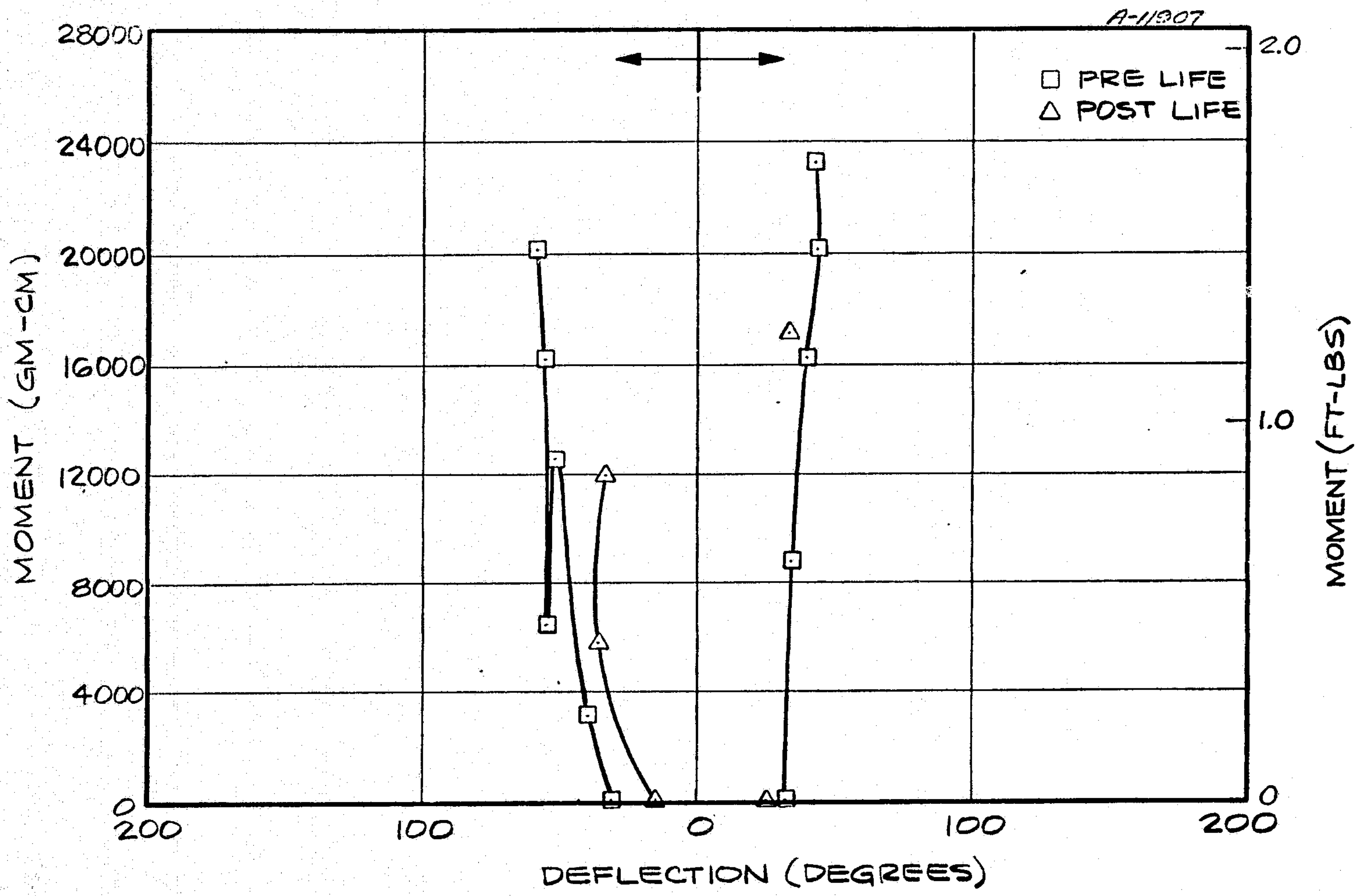



Figure 5-26. Mobility test of thermal/pressure glove wrist.

The graphs for the ring finger (Figures 5-19 and 5-20) illustrate the same general trends with the stable range improving slightly from 30° to 38° and flexure moments increasing from 800 gm-cm (0.06 ft-lbs) at full deflection to 2750 gm-cm (0.20 ft-lbs), a 240 percent change. The drop in the end of the movement curve for the pressure/thermal glove is due to the pressure glove wall collapsing and the finger "swallowing" itself. Because the astronaut's finger would block such movement in actual usage, the realistic moment at full deflection would probably be equal to or slightly less than the maximum reached at 60° mark. The moment to extend the ring finger fully increased 115 percent.

The mobility of the little finger is presented in the next pair of Figures (Figures 21 and 22) and is the only finger in which the stable range degreased with the addition of the overglove.

Fully closed moment forces climbed from 800 gm-cm (0.60ft-lbs) to 2000 gm-cm (0.14 ft-lbs) with the pressure/thermal glove swallowing itself at about the 60° position. Opening forces were increased by 19 percent and in both cases the end of the stable range essentially marked the maximum open position.

The last four figures (Figures 23 through 26) show the data for the wrist joint first in flexion-extension and then in adduction-abduction. Virtually no change took place in the moments to reach full deflection on either axis and the only effect of the thermal glove was to slightly increase the stable range of the wrist. This is undoubtedly due to the loose, coincal shape of the thermal glove gauntlet which allows a maximum degree of freedom over the entire range of the wrist. This performance contrasts sharply with that of the tightly fitting finger which seriously degraded mobility with the exception of thumb mobility.

Post-Life Test Mobility

The mobility of the glove was not significantly altered at the end of the life testing. The data for the post-life test is plotted concurrently with the pre-life test data. In two cases, the ring and little finger, the moments decreased, and for the index and middle finger the moments increased. The thumb and wrist on both axis of movement remained virtually unchanged. These differences are most likely the result of testing variables or a change in the measured moment arm of the finger. This would occur as the fabric "broke in" and began bending in a more continuous arc rather than at just one location as it had a tendency to do prior to the life test.

To determine the actual causes of the higher moments in the fingers, the Phase I thermal glove was disassembled and fitted onto the pressure glove in stages and moment forces measured as the layers were cut away. The absolute test volues are presented in Table 5-1. The percentage departure from the baseline pressure glove is shown in Figure 5-27 which charts the decrease in bending moment. In order to identify the various states of disassembly noted alphabetically in Figure 5-27 and Table 5-1, the following definitions are employed:

A. Thermal Glove I layup

B. Thermal Glove IA layup

C. Outer shell seam cut — length 2-1/4 inches each side

D. Outer shell completely removed

E. MLI removed

F. Felt removed — leaves only inner shell

G. Inner shell removed — leaves only pressure glove.

TABLE 5-1. VARIATION IN BENDING MOMENT FORCES IN THERMAL GLOVE ASSEMBLE WITH REMOVAL OF VARIOUS LAYERS (angular rotation — 90° — lever arm 7.2 cm (2.8-inch)

| Configuration | Bending Force Grams | (pounds) | Percentage Increase From Baseline Pressure Glove, % |
|---|---|---|---|
| A | 400 | (0.88) | 135 |
| B | 350 | (0.77) | 106 |
| C | 330 | (0.73) | 94 |
| D | 320 | (0.70) | 88 |
| E | 300 | (0.66) | 77 |
| F | 260 | (0.57) | 53 |
| G | 170 | (0.37) | 0 |

Configurations A and B reflect the finger layup for glove I and IA, respectively. The primary difference between the two lies in the felt. In the latter case, the felt has been cut forming a 3.18mm (0.125-inch) gap across the glove at the second metacarpal joint. This technique was responsible for a 29 percent decrease in bending moments.

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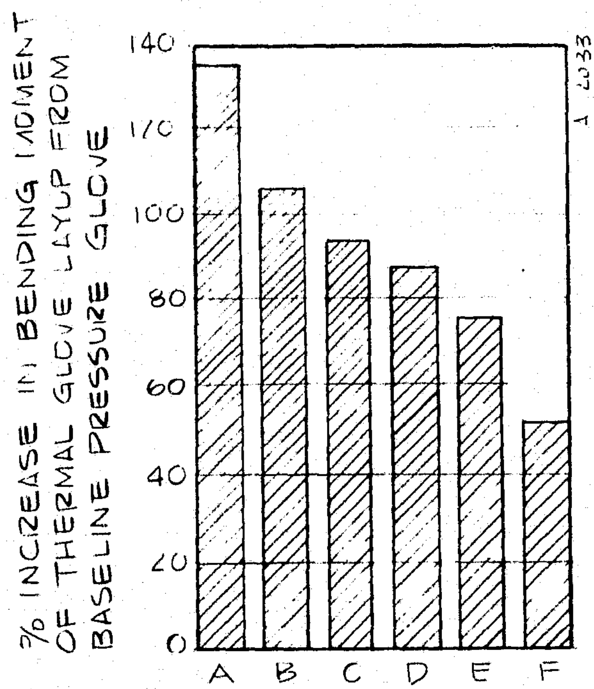


Figure 5-27. Increase in thermal glove bending moments above baseline pressure glove at various stages of disassembly.

The outer shell was only responsible for 18 percent of the increase in bending moment, while the total insulation shell (MLI and felt) reflected 35 percent of the net increase. The inner shell reflected the largest incremented moment. Apparently, the inner shell, designed to fit the pressure glove snugly, is acting somewhat as restraint layer. The relative interference between the inner shell of the thermal glove and the outer shell of the pressure glove is responsible for this increased moment.

In summary, it appears that a substantial reduction in moments can be achieved eliminating the inner shell. This can be done if the pressure glove does not leak gases into the primary insulators. Cutting the felt at the second metacarpal joint is justified by the decrease in bending moments. Additionally, it would appear that comgining the design of the pressure glove and thermal glove moment balancing could be achieved to increase in glove mobility.

## 5.6 TACTILITY TESTING

The tactility of the pressure glove and pressure/thermal glove combination was tested by using a set of nine standard aircraft control knobs which are designed for rapid shape recognition (see Figure 5-28). A total of six subjects were tested wearing the Phase I pressure glove to establish the baseline tactile scores (Table 5-2) and the same subjects were then retested wearing the pressure/thermal glove ensemble both before and after the life test.

A brief period of familiarization with the objects was allowed prior to each test. The objects were then firmly fixed in a glove box and the test conducted at -4 psig internal glove pressure. The subjects were not permitted to view the objects during the test, but were given sketches of the shapes (Figure 5-28) to aid in identification. Each subject was limited to 30 seconds for each identification.

The techniques of identification of the objects was a matter of personal preference and ranged from simply grasping the object hard to transmit tactile information to using the glove fingertips to lightly outline the object and secure its shape by the resultant gross hand movements. In all cases scores reported were good with little or no degradation due to the thermal glove evidenced. Familiarly with the shapes decidely improved the speed and accuracy of identification with experienced subjects able to identify any of the objects in several seconds.

The results of the three series of tests along with the individual scores are shown on the following page. From the baseline performance of 43 correctly identified out of 45 to the

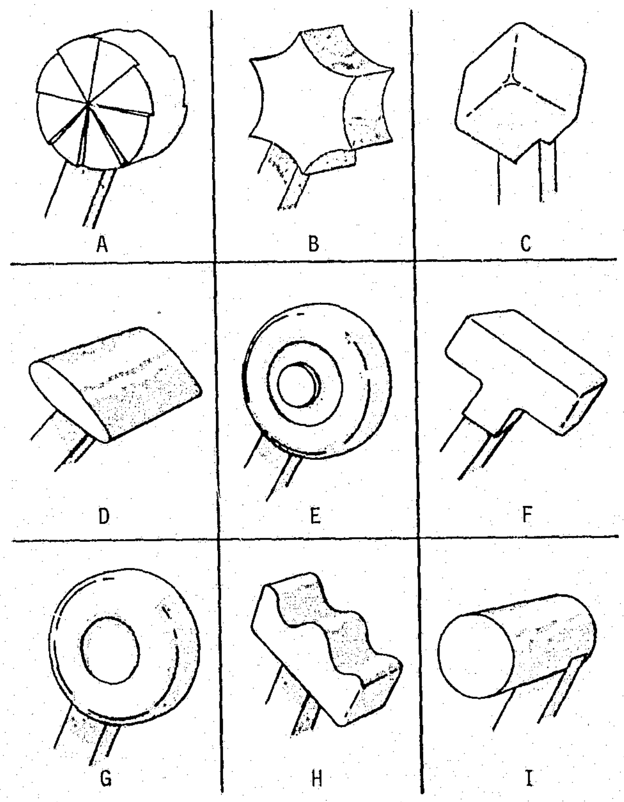


Figure 5-28. Representative aircraft control knobs to be used in tactile identification tests.

pre-life test score of 38 out of 45 is a change of only 12 percent. Post-life test scores were perfect which was a 5 percent improvement from the baseline test.

TABLE 5-2. TACTILITY TEST SCORES

| Subject | Pressure Glove Baseline Test | | Pre-life Test Thermal Glove | | Post-life Test Thermal Glove | |
|---|---|---|---|---|---|---|
| W. E. | 9/9 | 100.0% | 9/9 | 100.0% | 9/9 | 100% |
| W. S. | 8/9 | 88.8% | 5/9 | 55.5% | 9/9 | 100% |
| G. T. | 9/9 | 100.0% | 7/9 | 77.7% | 9/9 | 100% |
| R. A. | 8/9 | 88.8% | 8/9 | 88.8% | 9/9 | 100% |
| J. F. | 9/9 | 100.0% | 9/9 | 100.0% | 9/9 | 100% |

Statistical analyses were performed to determine if any significant difference occurred between the baseline and the pre-life test or between the pre- and post-life data. For the case of the baseline versus the pre-life test data, the Student's t method for small populations indicated with a 95 percent confidence limit that the difference between the two scores is insignificant. For the pre- and post-life test data, a 99 percent confidence level was verified using the same technique indicating that no statistically significant difference existed.

Analyses using normal distribution methods for large populations proved unsatisfactory due to the limited size of the data sample.

The conclusion drawn from the tactility tests was that with the addition of the thermal glove, no significant degradation on tactility occurred for objects of the size and design likely to be encountered by an astronaut in the performance of his EVA activities. The evidence pointed to the fact that experience and familiarity with the objects for outweighed any changes in tactility brought about by the thermal glove.

## SECTION 6

## CONCLUSION

The purpose of this program was to develop, fabricate and test a thermal protective EV overglove (Glove I) which was designed to fit a government furnished pressure glove and then to fabricate and deliver one pair of upgraded gloves based on the results of Glove I test data.

The thermal glove program clearly demonstrated that most design objectives were achieved, with the one exception being glove mobility. The following conclusions can be made:

1. Thermal Protection — The glove, theoretically, satisfied all of the thermal requirements. The hot bar design test was run to check experimentally the severest design condition. It was found that the glove before and following life cycling permitted acceptable temperatures at the glove/skin interface.

2. Tactility — The presence of the thermal glove did not degrade pressure glove tactility by more than the acceptable 10 percent value.

3. Mobility — The thermal glove, in general, was found to degrade pressure glove mobility by more than the acceptable 10 percent value. Not all glove areas were affected. Wrist mobility was virtually unchanged. However, finger mobility was incumbered by the thermal glove principally by the presence of the inner shell. Removal of the inner shell would bring about a 50 percent reduction of excess bending moment.

   An interesting phenomena occurred wherein the thermal overglove thumb apparently exhibited inverse torque characteristics to the pressure glove thumb. The result of this was a reduction in overall torque and an increase in range for the complete assembly over the pressure glove thumb alone. This technique could be applied by intent to the overall design with a final "tweaking" of the pressure glove finger restraint to optimize torque and range for the glove system. Such adjustments in the pressure glove were beyond the scope of this program.

4. Life Cycling — The thermal glove completed life cycling with minimal problems. All materials and assembly techniques held up well throughout the tests.

5. Comfort — The thermal glove/pressure glove ensemble was tested for comfort during the manned lifecycle tests. The test subjects found no problem with the thermal glove although they did report difficulties with pressure points on the pressure glove which was independent of the thermal glove.

As a result of the design, fabrication, and testing, the following observations are made.

Design

a. The thermal glove was designed essentially as three basic shells (inner shell, insulative shell, and outer shell).

b. The glove was made as thin as possible so as to avoid excessive bulk.

c. Fingers are tailored slightly curved to decrease excess material in glove and to reduce bending moments(see Figure 1-1).

Materials

a. The glove design features extensive use of Nomex felt as a primary means of insulation. The felts thermally protected the glove and transfered tactile information, but it did cause an increase in bending moment.

b. Orthofabric was selected as the outer fabric. This material held up well in all aspects.

c. Kevlar was used in the outer surface of the palm area of the glove. This material proved quite satisfactory. However, the friction coating did not survive life and tactility testing. A different silicone coating and application procedure was used in the final Glove IA fabrication.

d. The nylon ripstop survived all testing as expected.

e. Aluminized mylar held up quite well during life cycling if and only if it was absolutely free of small holes, or cuts in it. Pieces containing imperfections by stitching through MLI into felt were completely destroyed during life cycling. Hence, such layers were eliminated in the final design. (Because glove insulation was greater than minimal requirements, elimination of the single layer of MLI did not jeapordize glove thermal design).

Fabrication

a. The use of low and high density felts in lieu of MLI insulating layers resulted in a lower cost and more durable glove when compared with the A7L thermal glove. However, costs can be significantly reduced by the use of an integrated cover layer/insulator fabric (see Section 7, Recommendations).

b. Fabrication was complicated by the dissimilarities between the GFE pressure gloves left and right hand finger sizes.

c. A significant cost reduction could be effected if the inner shell were eliminated. Considerable hand work is required to tie the insulation to the inner shell.

Appearance

a. The appearance of the glove satisfied our aesthetic requirements. The gold (Kevlar) on white (Orthofabric) was aesthetically pleasing and the large quantity of white fits nicely with anticipated spacesuit systems.

## SECTION 7

## RECOMMENDATIONS

The thermal overglove met or exceeded all design requirements (i.e., manned life test, tactility test, and comfort tests) with the exception of mobility. Specifically, finger torques were adversely affected, and it is in this area wnere the greatest improvement is needed.

In order to establish some rationale for improving glove mobility, a special test was performed. This test, which is discussed in detail in Section 5-5, determined the bending moment required to flex a layup thermal finger through an angle of 90° for several different thermal glove finger conditions. The results of this test indicated that the primary cause of decreased finger mobility and increased bending moments was the inner shell acting as an additional pressure glove restrrint layer. The data indicate that moments can be decreased by 50% when this layer is eliminated. Technically, this layer can be eliminated for pressure gloves with low leak rates.

The following recommendations are presented based on the experimental observations. They are aimed at increasing the performance of the glove and dramatically decreasing the cost of manufacture.

1. Employ a seamless dipped bladder design concept when fabricating pressure gloves (see Figure 7-1) to decrease glove leak rate.

2. Eliminate the inner shell of the thermal glove. An integral, nonleak bladder will eliminate the need for the inner shell of the thermal glove.

3. Integrate outer fabric and insulation shell (felt) by developing a new fabric. This fabric would contain 50 percent Gortex, 25 percent Nomex and 25 percent Kevlar as found in Orthofabric. However, the opposite side is woven such that a Nomex fiber forms a dense pile reminiscent of Velcro loop pile. The loops will act as thermal standoff. Preliminary conductivity tests of a nylon Velcro layup yield overall conductances only 20 percent higher than the Orthofabric and low density Nomex felt layup. Hence, it would appear that this proposed fabric could be used for a glove layup as shown in Figure 7-2.

ht14ms

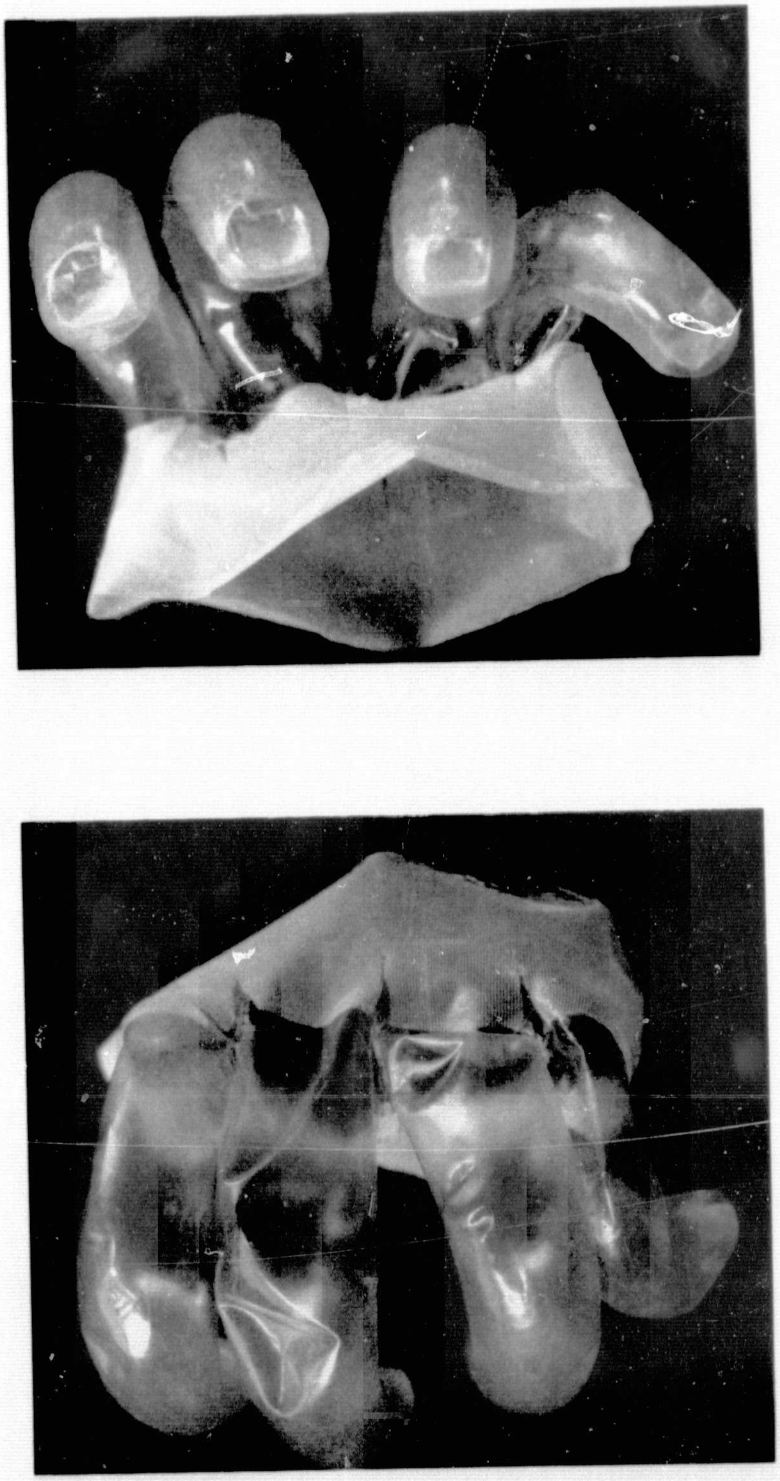

Figure 7-1. Four finger urethane bladder for pressure glove layup.

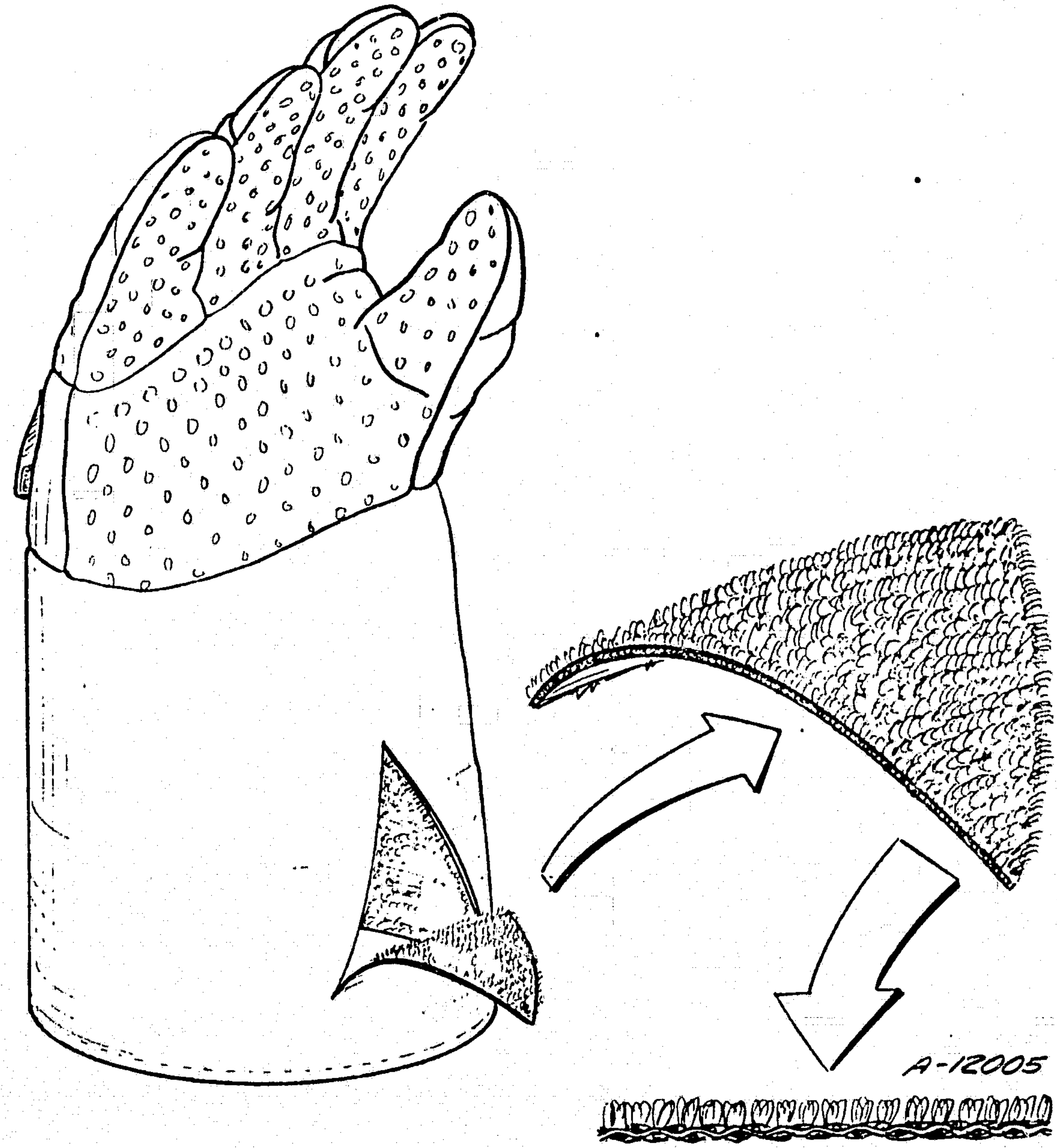


Figure 7-2. Recommended glove design.

4. Investigate the use of the proposed fabric to full space suit ensembles. This fabric combines the desired exterior for solar and space irradiation plus the toughness required for EV efforts. Additionally, this fabric would bring about a great cost savings because it would eliminate all the extra labor associated with placing MLI or felt in the insulative shell.

5. The friction layer on the thermal glove should be eliminated in favor of a local high friction dots as shown in Figure 7-2. Continuous coating on the fabric "locks up" the fiber so they cannot shift under stress thereby increasing the bending moment. This new approach should provide adequate friction to handle tools while still maintaining good fiber extensibility.

6. Apply Velcro hooks to pressure glove at the appropriate position to secure the thermal glove to the pressure glove. The Velcro hooks will attach to the proposed fabric loops. This will eliminate the layup of the Velcro loop now provided and somewhat decrease glove thickness.

7. The thermal/pressure glove should be designed as a system. The torque and range characteristics then can be improved by adjustment of overglove and pressure glove neutral positions. One glove layer can be made complimentary to the other, resulting in increased range and lower torques. Feasibility of the approach was demonstrated in the Phase I thermal Pressure glove where thumb range and torque was actually improved over the pressure glove without the thermal overglove installed.

## REFERENCES


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# APPENDIX A

# THERMAL GLOVE ASSEMBLY PROCEDURES

## APPENDIX A

## FABRICATION PROCEDURES

The pair of thermal gloves are fabricated as three separate gloves which become united during fabrication. The basic steps involved are depicted in a number of figures located in Section A.3. The list of glove materials are presented in Section A.1 and the glove assembly procedures are presented in Section A.2. This particular assembly was established to fit the GF pressure gloves. Left hand patterns are formed by reversing the right hand patterns which are shown in Appendix A.3.

### A.1 MATERIAL LIST

The actual materials used in the fabrication of glove IA are listed below:

1. Nylon ripstop, grey, flame resistant neoprene coated.
2. Thread, Kevlar 29, size 0, BX finish.
3. Nomex felt, style 71004, white, 166 ± 0.030-inch (back & gauntlet).
4. Orthofabric (2 ply fabric with 400 denier 2 ply Goretex, 200 denier, 2 ply Nomex and 400 denier Kavlar 29, 16/2 Patt, 39 Epi x 33 EPL).
5. Sergene, anti-fray solution.
6. Nomex felt, 9.90 $oz/yd^2$ white, 0.1-inch (Palms)
7. Flame resistant neoprene*.
8. Velcro loop tape, nylon, white, standard backing.
9. Velcro hook tape, nylon, white, standard backing.
10. Adhesive, neoprene type, 2 part, N-136.
11. Mylar, aluminized both sides, 0.0005-inch.
12. Kapton aluminized tape, 1 mil, with silicone pressure sensitive adhesive.

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*A. Little, Inc. cement thread sealant with trimene base catalyst mixed 100 to 1, thinned with 1cc MEK and 4cc Toluene, cured at 150° to 170° for 3 hours.

13. Scrim, polyester, sensitive adhesive, nonwoven, 0.001-inch, 15 gms/yd$^2$.

14. Kevlar 29, 5 Z twist, with Nomex warp blend, 2X2 T will weave, 5.25 oz/yd$^2$, fire resistant fabric.

15. Silicone rubber, 615 parts, A and B, with SS-4155 silicone primer.

## A.2 ASSEMBLY PROCEDURES

The reader is referred to the figures presented in Section A.3 which depict patterns and subassemblies at various stages of fabrication when using the inner shell. The detailed list of materials was presented in Section 4.1. All item numbers referred to in the following refer to those numbers.

<u>I. Inner Shell</u>

A. Pattern fingers #1 — #4 and palm side of thumb, sized to pressure glove #1A.

   a. Cut from item 1.

   b. Stich 1/8-inch seams neoprene sides together.

   c. Cut wedges.

   d. Stitch crotches together.

B. Pattern back of thumb and hand, sized to pressure glove #1A.

   a. Cut from item 1.

   b. Cut strap opening in back of hand, 3-1/2-inch long X 7/8-inch wide to correspond with pressure glove strap.

   c. Face opening to outside with item 1, 5-inch X 2-1/2-inch to finish with neoprene toward hand.

   d. Cut back of hand from item 3 and secure under facing.

   e. Top stitch 1/2-inch from edge of a 1/2-inch allowance.

   f. Stitch palm of thumb and fingers #1 through #4 to hand.

   g. Secure item 3 on seam allowance with back stitch hand tack.

C. Pattern gauntlet sized to pressure glove #1A.

   a. Cut from item 1.

   b. Stitch side seam and attach to hand.

D. Pattern cuff

a. Cut cuff from items 1 and 4.

b. Seal edges of item 4 with item 5.

c. Stitch cuff to bottom of gauntlet, white side toward wrist.

II. Felts

A. Pattern palm, palm of finger #1 through 4 and thumb palm 1/4-inch narrower than inner shell pattern from item 6.

a. Stitch felts to inner shell, break stitching at 2nd metacarple.

b. Cut 1/8-inch tear drop slash across felts at 2nd metacarple, do not slash thumb felt.

c. Rough felt over threads to avoid thermal shorts.

d. Attach felts (fingers to palm) with hidden hand stitch per item 2, no threads showing.

B. Bond item 8 with item 11 inside inner shell at finger tips and at 1st metacarple. Bond item 9 with item 10 at fingertip and 1st metacarple of pressure glove.

C. Cut gauntlet same size as inner shell quantlet.

a. Overlay side seam and stitch with item 2.

b. Hand tack, per item 2, gauntlet felt to hand felts.

c. Hand tack bottom of gauntlet felt to gauntlet rip-stop per item 2.

d. Turn inner shell to neoprene side and fill seams and needle thread holes with item 7. Cure 150°F to 170°F for 3 hours.

III. Multi-layer Insulation

A. Pattern item 11 and 13 from inner shell pattern, adjusting to 1/8-inch narrower around finger edges.

a. Layup 3 layers of item 11 and 2 layers of item 13 in alternate layers starting with item 11.

b. First 4 layers are tapered away from glove; 5th layer meets threads under seam allowance.

c. Attach to inner shell with small pieces of item 12, cover seam and seam allowance with item 12.

B. Pattern and cut back of hand and thumb of item 11.

a. Attach to fingers and enclose cut edges with item 12.

## IV. Outer Shell

A. Pattern thumb and finger palms 1/16-inch wider all edges than inner shell. Pattern back of thumb and hand 1/16-inch wider all edges than inner shell.

a. Cut palms from item 14. Seal edges with item 5.

b. Cut backs from item 4. Seal edges with item 5.

c. Stitch teflon side to kevlar per inner shell A.

d. Press seams open, cut wedges, seal per item 5.

e. Face strap opening so that neoprene side of facing folds towards glove.

B. Flap

a. Layup from pressure glove to outside: Item 1, item 3, item 11, and item 4.

b. Stitch 4-1/4-inchs of item 8 to 5-inch X 2-3/4-inch of item 1.

c. Cut item 4, 5-1/4-inch X 3-inchs to finish 4-1/2-inches X 2-1/4 inches so that item 4 forms 45° angle corner when stitched to item 1.

e. Fill pocket with item 3 and item 11.

f. Stitch 4-1/4-inches item 9 under strap opening.

g. Tack stitch flap to Orthofabric gauntlet.

h. Seal pocket with item 7. Turn.

C. Pattern Gauntlet.

a. Cut gauntlet of item 4.

b. Stitch side seams and attach to glove.

D. Hem.

a. Cut gauntlet felt 1-inch shorter than Orthofabric gauntlet.

b. Turn a clean edge finish on outer gauntlet, then turn again to enclose cut off of cuff 1/2-inch.

c. Top stitch.

E. Coat palm and finger palms per item 15. Cure 4 hours @ 170°.

F. Attach inner shell and outer shell.

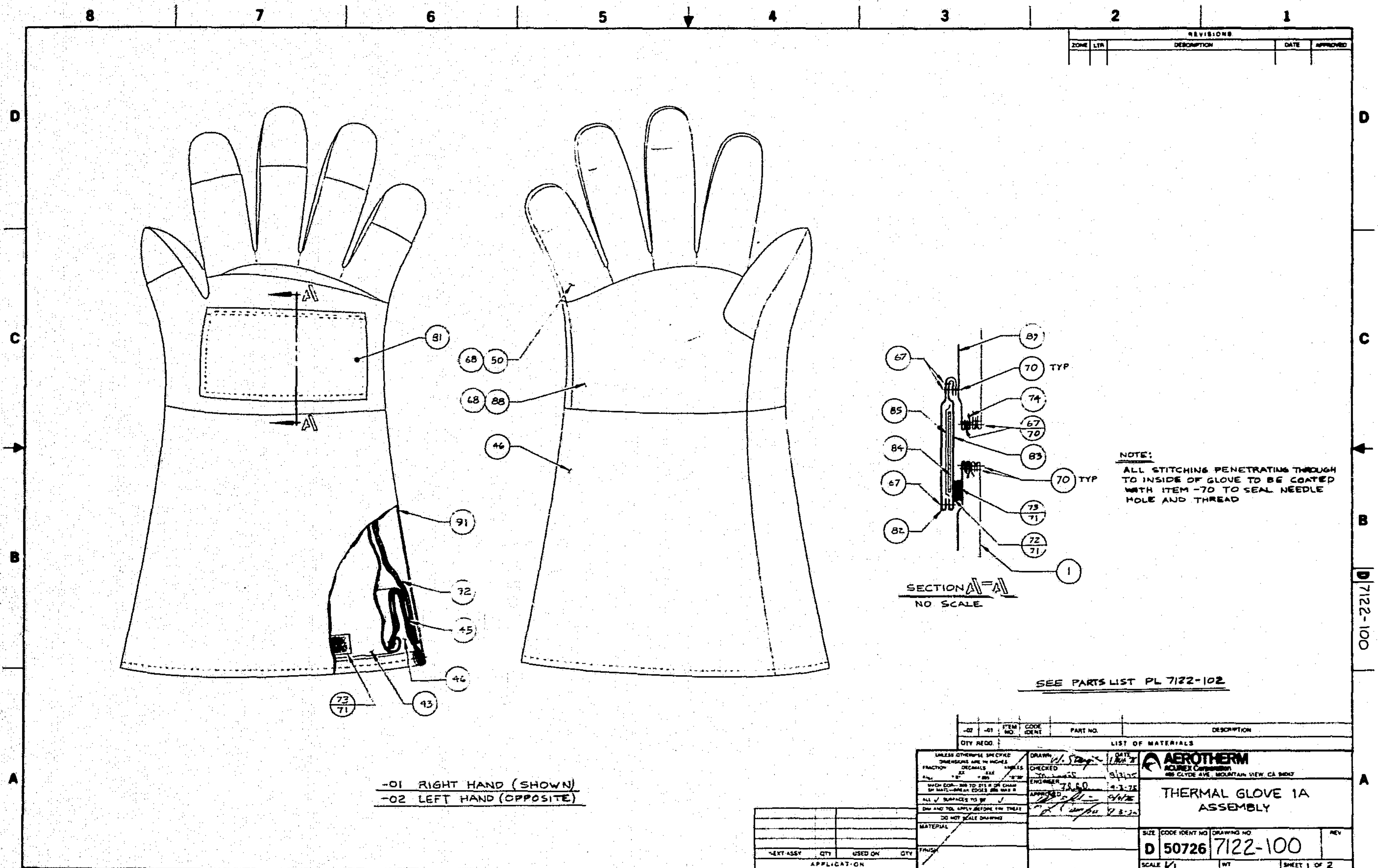
a. Bond item 9 to gasket on pressure glove at 4 equidistant spots with item 10. Bond item 8 to bottom of ripstop gauntlet at corresponding spots with item 10.

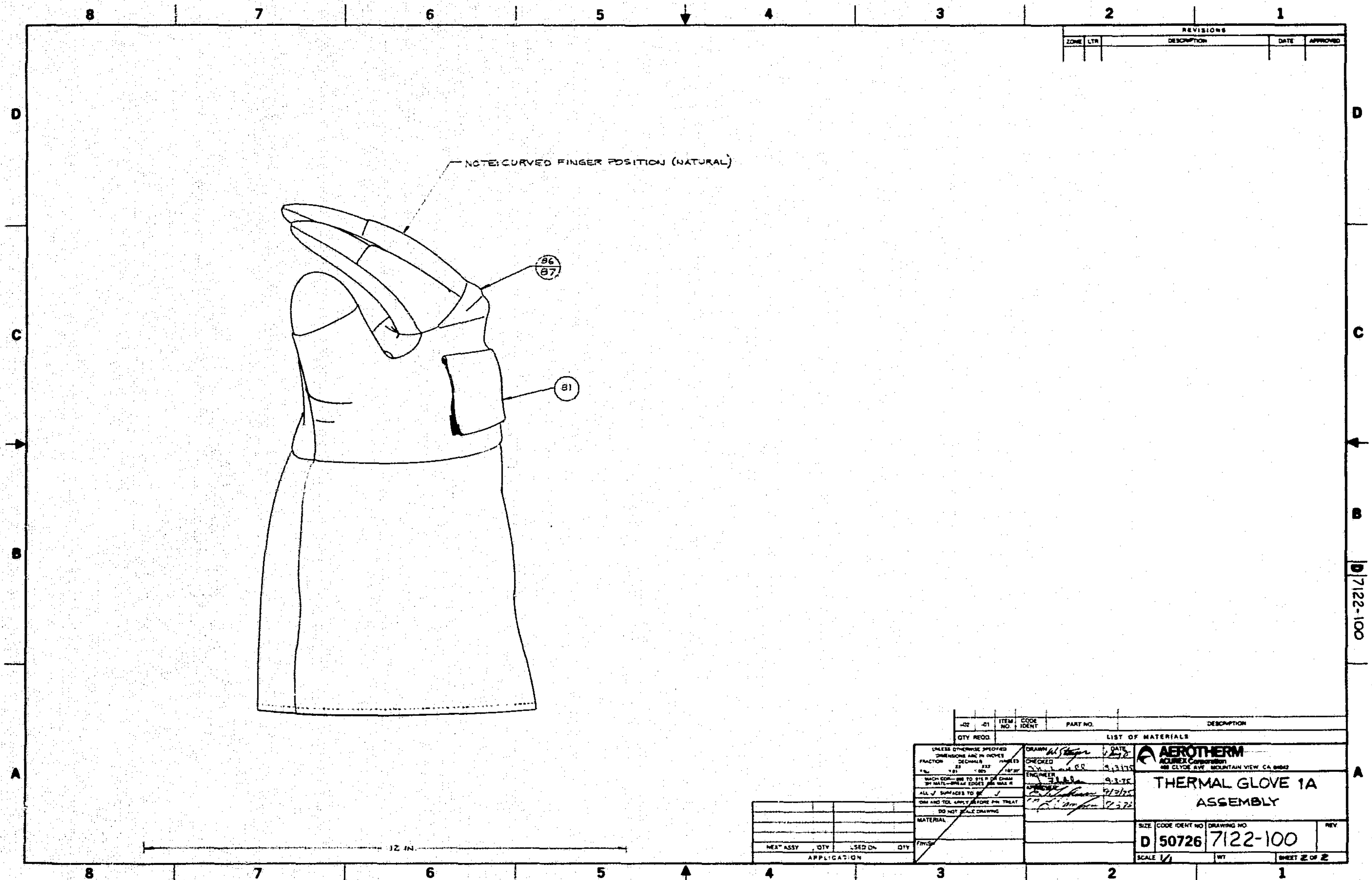
b. Stitch inner shell and outer shell together around strap opening .

c. Seal stitches per item 7.

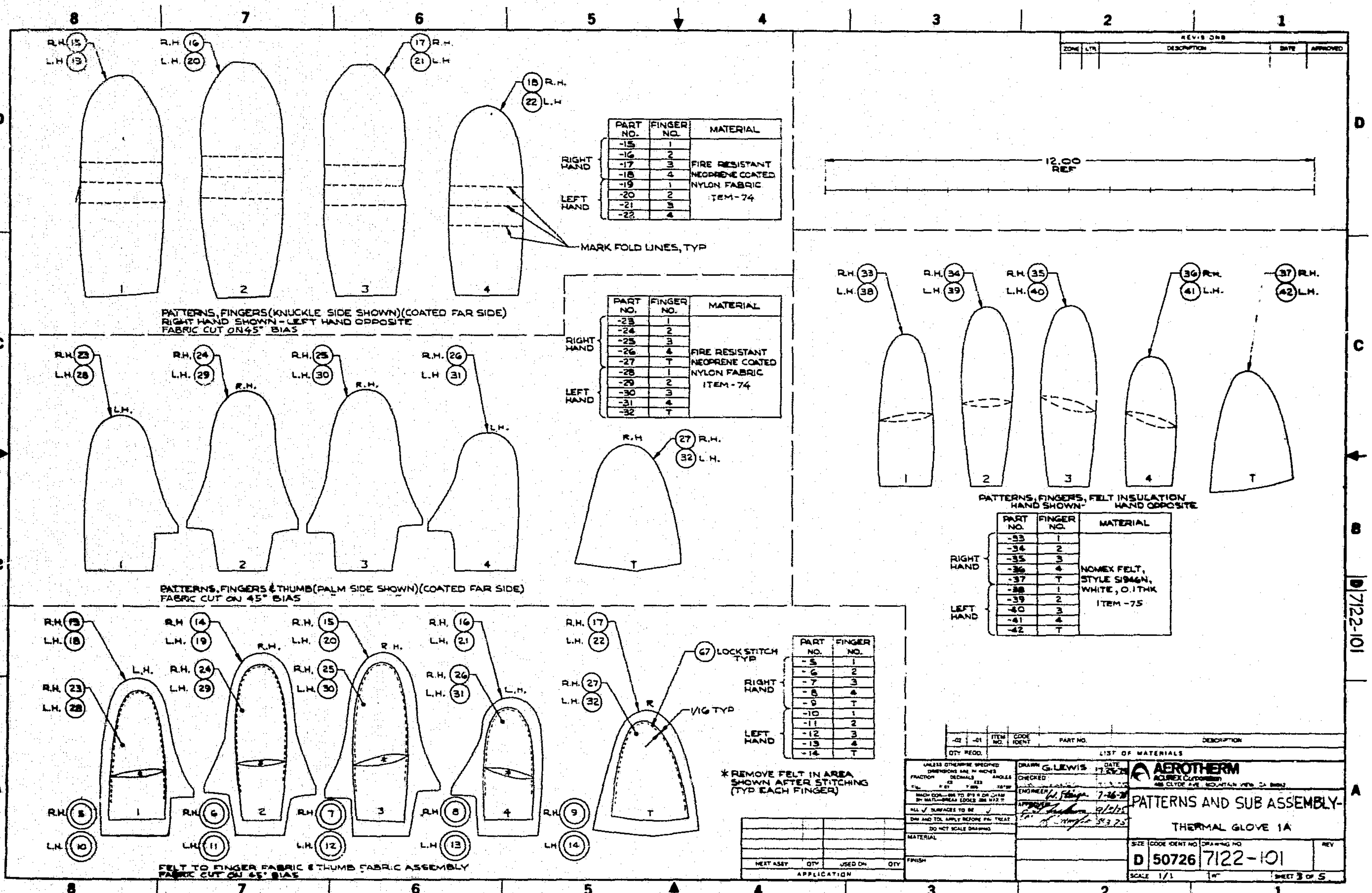
## A.3 ASSEMBLY DRAWINGS

The assembly drawings are shown in the following pages.


REVISIONS
ZONE LTR DESCRIPTION DATE APPROVED
NOTE:
ALL STITCHING PENETRATING THROUGH TO INSIDE OF GLOVE TO BE COATED WITH ITEM -70 TO SEAL NEEDLE HOLE AND THREAD
SECTION A-A
NO SCALE
SEE PARTS LIST PL 7122-102
-01 RIGHT HAND (SHOWN)
-02 LEFT HAND (OPPOSITE)
LIST OF MATERIALS
AEROTHERM
ACUREX Corporation
THERMAL GLOVE 1A
ASSEMBLY
D 50726 7122-100
SCALE 1/1
SHEET 1 OF 2
D 7122-100



NOTE: CURVED FINGER POSITION (NATURAL)
86
87
81
12 IN.
REVISIONS
ZONE
LTR
DESCRIPTION
DATE
APPROVED
-02
-01
ITEM NO.
CODE IDENT
PART NO.
DESCRIPTION
QTY REQD.
LIST OF MATERIALS
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
DO NOT SCALE DRAWING
MATERIAL
FINISH
NEXT ASSY
QTY
USED ON
QTY
APPLICATION
DRAWN
DATE
CHECKED
9-3-75
ENGINEER
9-3-75
AEROTHERM
ACUREX Corporation
CLYDE AVE. MOUNTAIN VIEW, CA
THERMAL GLOVE 1A
ASSEMBLY
SIZE
CODE IDENT NO
DRAWING NO.
REV.
D
50726
7122-100
SCALE 1/4
WT
SHEET 2 OF 2
D 7122-100




| | PART NO. | FINGER NO. | MATERIAL |
|---|---|---|---|
| RIGHT HAND | -15 | 1 | FIRE RESISTANT NEOPRENE COATED NYLON FABRIC ITEM-74 |
| | -16 | 2 | |
| | -17 | 3 | |
| | -18 | 4 | |
| LEFT HAND | -19 | 1 | |
| | -20 | 2 | |
| | -21 | 3 | |
| | -22 | 4 | |

| | PART NO. | FINGER NO. | MATERIAL |
|---|---|---|---|
| RIGHT HAND | -23 | 1 | FIRE RESISTANT NEOPRENE COATED NYLON FABRIC ITEM-74 |
| | -24 | 2 | |
| | -25 | 3 | |
| | -26 | 4 | |
| | -27 | T | |
| LEFT HAND | -28 | 1 | |
| | -29 | 2 | |
| | -30 | 3 | |
| | -31 | 4 | |
| | -32 | T | |

| | PART NO. | FINGER NO. | MATERIAL |
|---|---|---|---|
| RIGHT HAND | -33 | 1 | NOMEX FELT, STYLE S1946N, WHITE, 0.1THK ITEM -75 |
| | -34 | 2 | |
| | -35 | 3 | |
| | -36 | 4 | |
| | -37 | T | |
| LEFT HAND | -38 | 1 | |
| | -39 | 2 | |
| | -40 | 3 | |
| | -41 | 4 | |
| | -42 | T | |

| | PART NO. | FINGER NO. |
|---|---|---|
| RIGHT HAND | -5 | 1 |
| | -6 | 2 |
| | -7 | 3 |
| | -8 | 4 |
| | -9 | T |
| LEFT HAND | -10 | 1 |
| | -11 | 2 |
| | -12 | 3 |
| | -13 | 4 |
| | -14 | T |

* REMOVE FELT IN AREA SHOWN AFTER STITCHING (TYP EACH FINGER)

LIST OF MATERIALS

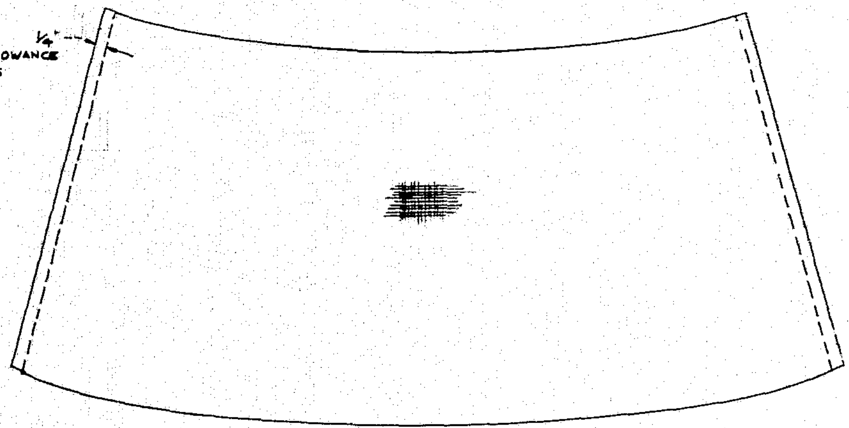
DRAWN G. LEWIS

AEROTHERM ACUREX Corporation

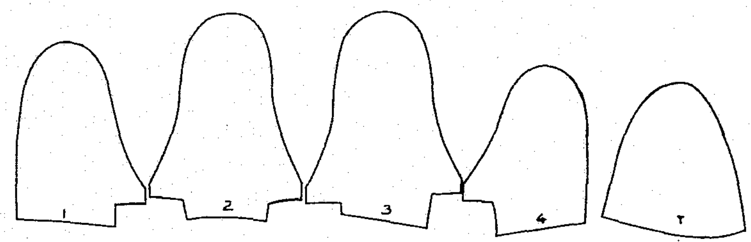
PATTERNS AND SUB ASSEMBLY- THERMAL GLOVE 1A

SIZE D | CODE IDENT NO 50726 | DRAWING NO 7122-101 | SCALE 1/1 | SHEET 3 OF 5

D 7122-101

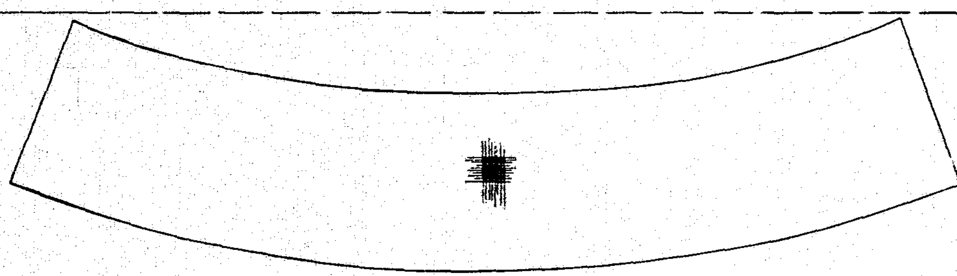



(43) PATTERN, GAUNTLET
MATERIAL: FIRE RESISTANT NEOPRENE
COATED NYLON FABRIC ITEM - 74




PATTERNS, FINGERS & THUMB OUTER FABRIC (PALM SIDE SHOWN)
LEFT HAND SHOWN-RIGHT HAND OPPOSITE
FABRIC CUT ON 45° BIAS

| | PART NO. | FINGER NO. | MATERIAL ITEM NO. |
|---|---|---|---|
| RIGHT HAND | -47 | 1 | -66 |
| | -48 | 2 | |
| | -49 | 3 | |
| | -50 | 4 | |
| | -51 | T | |
| LEFT HAND | -52 | 1 | |
| | -53 | 2 | |
| | -54 | 3 | |
| | -55 | 4 | |
| | -56 | T | |



(45) PATTERN, GAUNTLET CUFF
MATERIAL: FIRE RESISTANT NEOPRENE
COATED NYLON FABRIC ITEM - 74

(46) PATTERN, GAUNTLET CUFF OUTER FABRIC
MATERIAL: ITEM-65 ORTHO FABRIC

12" (REF)

| -02 | -01 | ITEM NO. | CODE IDENT | PART NO. | DESCRIPTION |
|---|---|---|---|---|---|
| QTY. REQD. | | | | LIST OF MATERIALS | |

| NEXT ASSY | QTY | USED ON | QTY |
|---|---|---|---|
| APPLICATION | | | |

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
MATERIAL
FINISH

| | | DATE |
|---|---|---|
| DRAWN | W. Stayer | 15 Aug 75 |
| CHECKED | | 9/3/75 |
| ENGINEER | | 9-3-75 |
| APPROVED | | 9/3/75 |
| | | 9-3-75 |

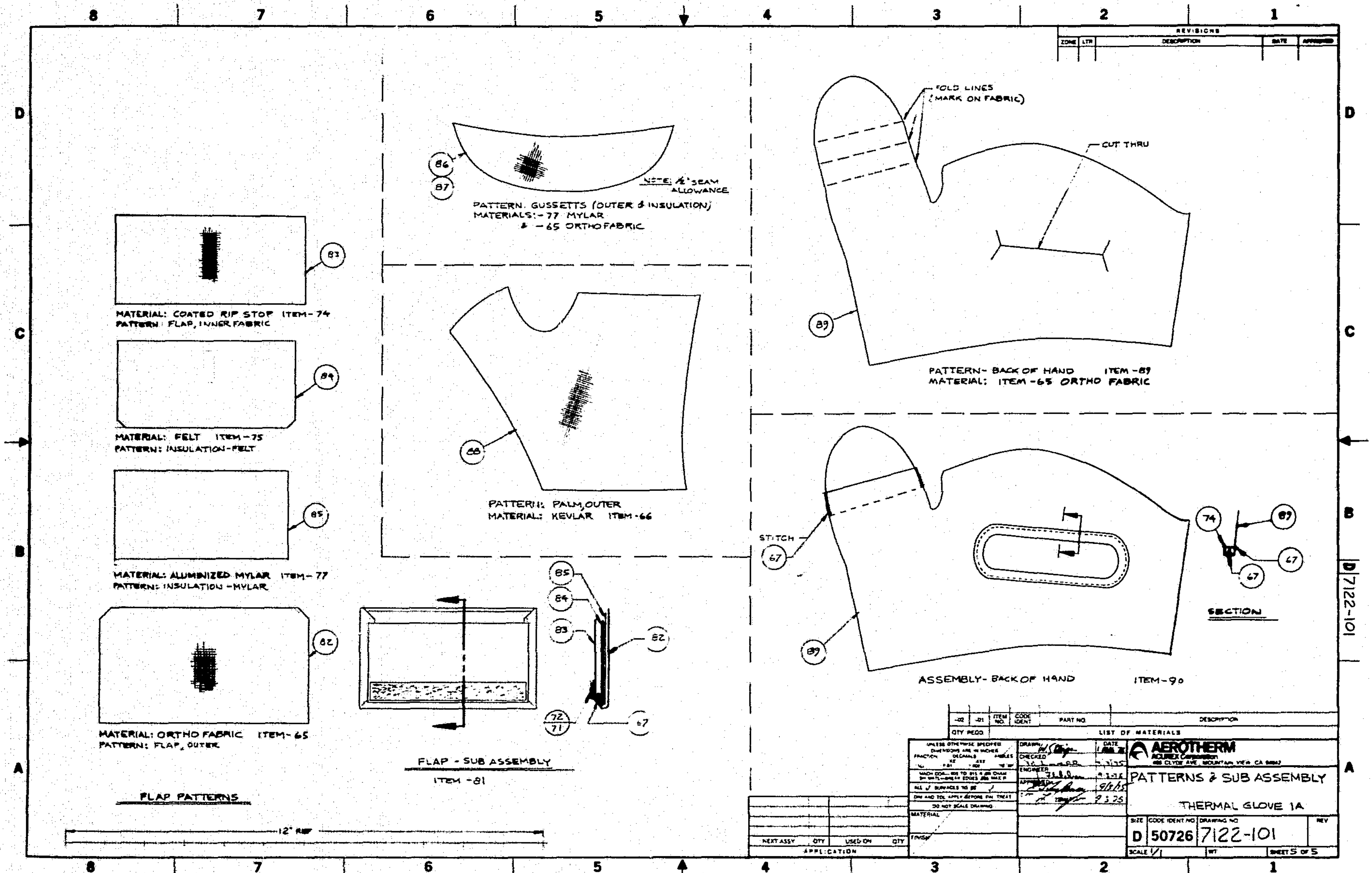
AEROTHERM
ACUREX Corporation
485 CLYDE AVE. MOUNTAIN VIEW, CA 94042

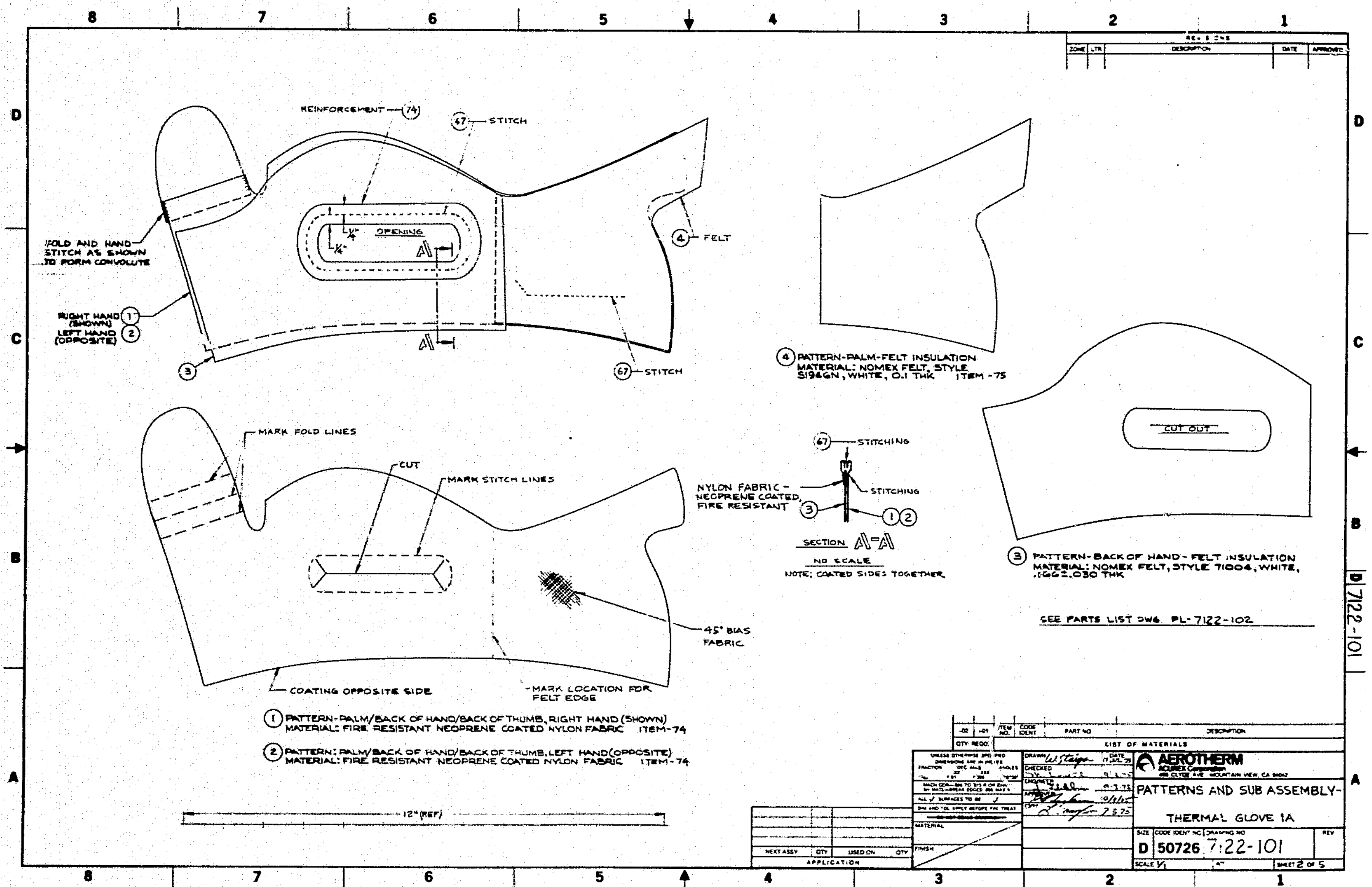
PATTERNS AND SUB ASSEMBLY-
THERMAL GLOVE 1A

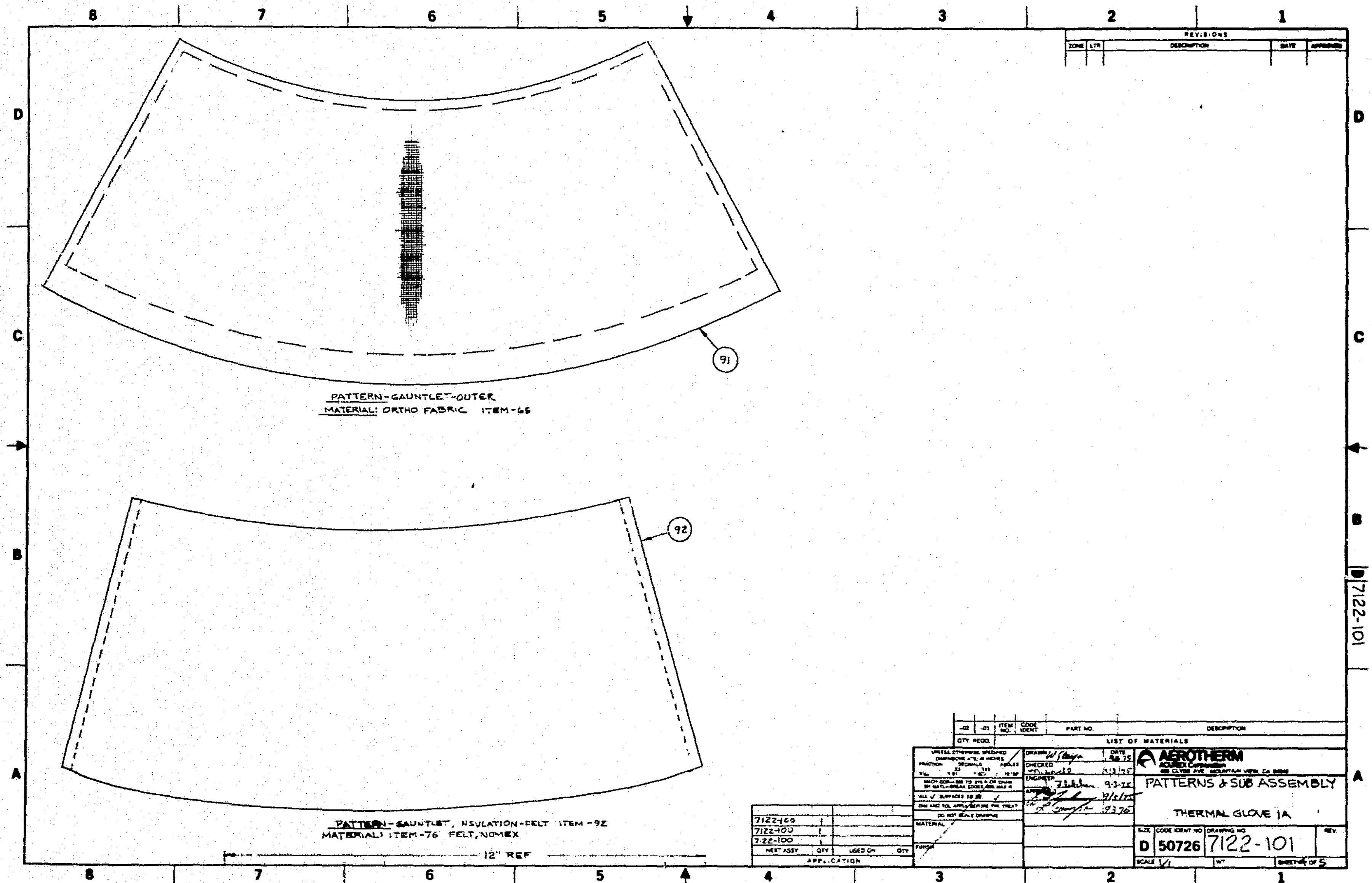
| SIZE | CODE IDENT NO. | DRAWING NO. | REV |
|---|---|---|---|
| D | 50726 | 7122-101 | |
| SCALE 1/1 | WT | SHEET 1 OF 5 | |

D 7122-101

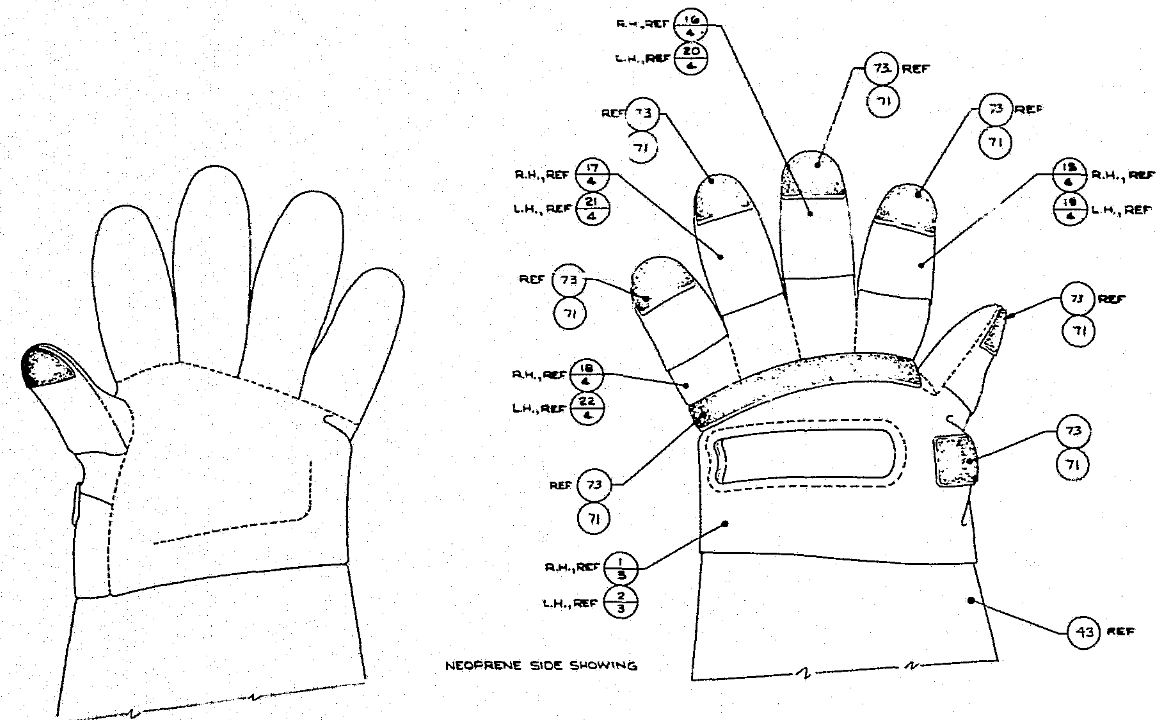
ORIGINAL PAGE IS OF POOR QUALITY




REINFORCEMENT 74
67 STITCH
OPENING
1/4"
1/4"
A
FOLD AND HAND STITCH AS SHOWN TO FORM CONVOLUTE
RIGHT HAND (SHOWN) 1
LEFT HAND (OPPOSITE) 2
3
4 FELT
67 STITCH
4 PATTERN-PALM-FELT INSULATION
MATERIAL: NOMEX FELT, STYLE S194GN, WHITE, 0.1 THK ITEM -75
MARK FOLD LINES
CUT
MARK STITCH LINES
45° BIAS FABRIC
COATING OPPOSITE SIDE
MARK LOCATION FOR FELT EDGE
1 PATTERN-PALM/BACK OF HAND/BACK OF THUMB, RIGHT HAND (SHOWN)
MATERIAL: FIRE RESISTANT NEOPRENE COATED NYLON FABRIC ITEM-74
2 PATTERN: PALM/BACK OF HAND/BACK OF THUMB, LEFT HAND (OPPOSITE)
MATERIAL: FIRE RESISTANT NEOPRENE COATED NYLON FABRIC ITEM-74
12" (REF)
67 STITCHING
NYLON FABRIC - NEOPRENE COATED, FIRE RESISTANT
STITCHING
3
1 2
SECTION A-A
NO SCALE
NOTE: COATED SIDES TOGETHER
CUT OUT
3 PATTERN-BACK OF HAND-FELT INSULATION
MATERIAL: NOMEX FELT, STYLE 71004, WHITE, .066-.030 THK
SEE PARTS LIST DWG. PL-7122-102
D 7122-101
ZONE LTR DESCRIPTION DATE APPROVED
ITEM NO. CODE IDENT PART NO DESCRIPTION
QTY REQD. LIST OF MATERIALS
NEXT ASSY QTY USED ON QTY
APPLICATION
MATERIAL
FINISH
DRAWN W. Staiger 17 JUL 75
CHECKED
ENGINEER
APPROVED
AEROTHERM
ACUREX Corporation
MOUNTAIN VIEW, CA
PATTERNS AND SUB ASSEMBLY-
THERMAL GLOVE 1A
SIZE D CODE IDENT NO 50726 DRAWING NO 7122-101 REV
SCALE 1/1 SHEET 2 OF 5



91
PATTERN-GAUNTLET-OUTER
MATERIAL: ORTHO FABRIC ITEM-65
92
PATTERN-GAUNTLET, INSULATION-FELT ITEM-92
MATERIAL: ITEM-76 FELT, NOMEX
12" REF
REVISIONS
ZONE LTR DESCRIPTION DATE APPROVED
ITEM NO. CODE IDENT PART NO. DESCRIPTION
QTY REQD. LIST OF MATERIALS
7122-100
7122-400
7122-100
NEXT ASSY QTY USED ON QTY
APPLICATION
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
DO NOT SCALE DRAWING
MATERIAL
FINISH
DRAWN
CHECKED
ENGINEER
DATE
9-3-75
AEROTHERM
ACUREX Corporation
PATTERNS & SUB ASSEMBLY
THERMAL GLOVE 1A
SIZE D
CODE IDENT NO 50726
DRAWING NO 7122-101
REV.
SCALE 1/1
SHEET 4 OF 5
D 7122-101




NOTE: SEE PARTS LIST PL 7122-102

| -02 | -01 | ITEM NO. | CODE IDENT | PART NO. | DESCRIPTION |
|---|---|---|---|---|---|
| QTY REQD. | | | | LIST OF MATERIALS | |

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
DO NOT SCALE DRAWING
MATERIAL
FINISH

NEXT ASSY | QTY | USED ON | QTY
APPLICATION

DRAWN W Staeger
CHECKED
ENGINEER
APPROVED

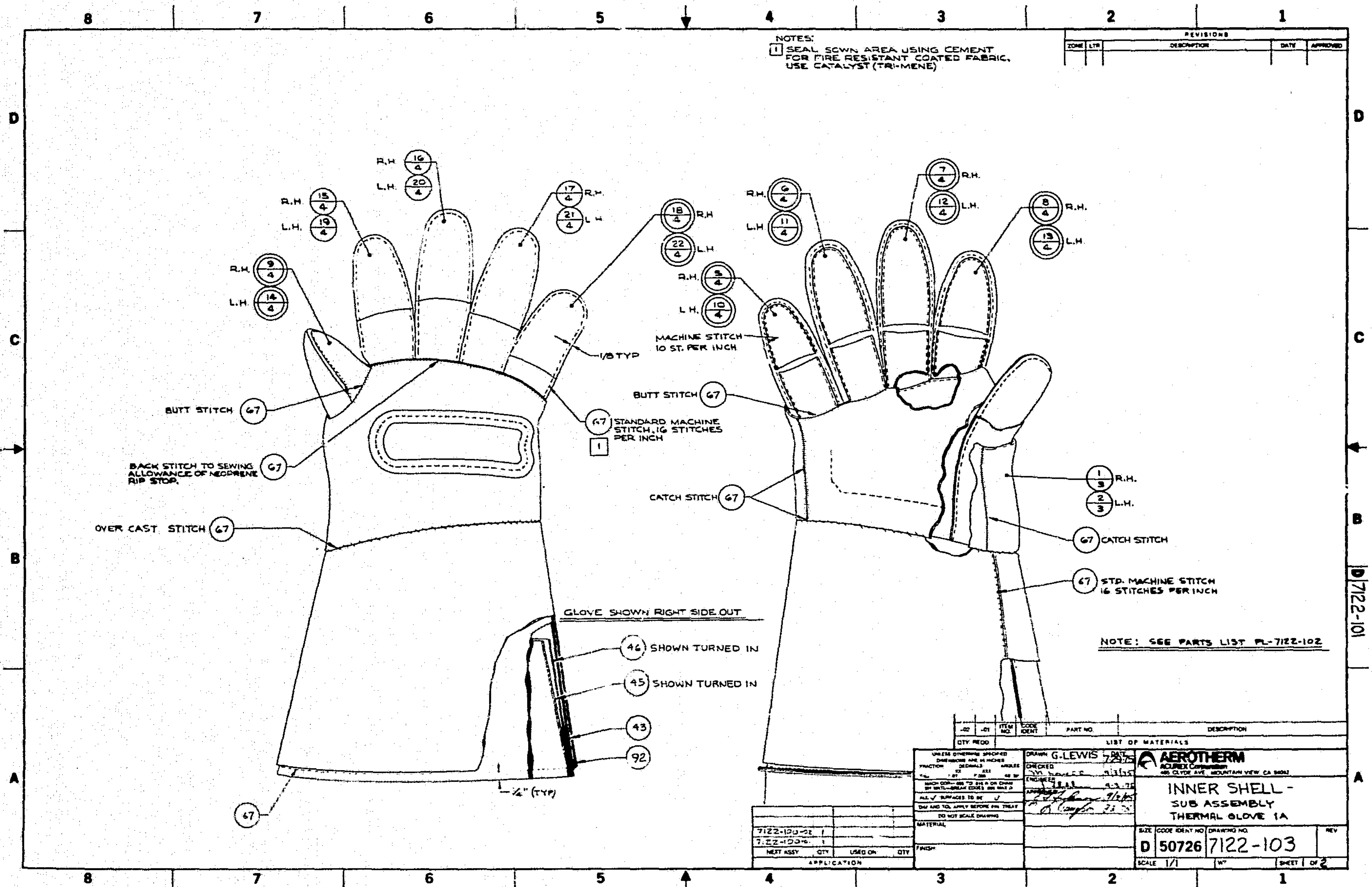
AEROTHERM
485 CLYDE AVE, MOUNTAIN VIEW CA

INNER SHELL-
SUB ASSEMBLY
THERMAL GLOVE 1A

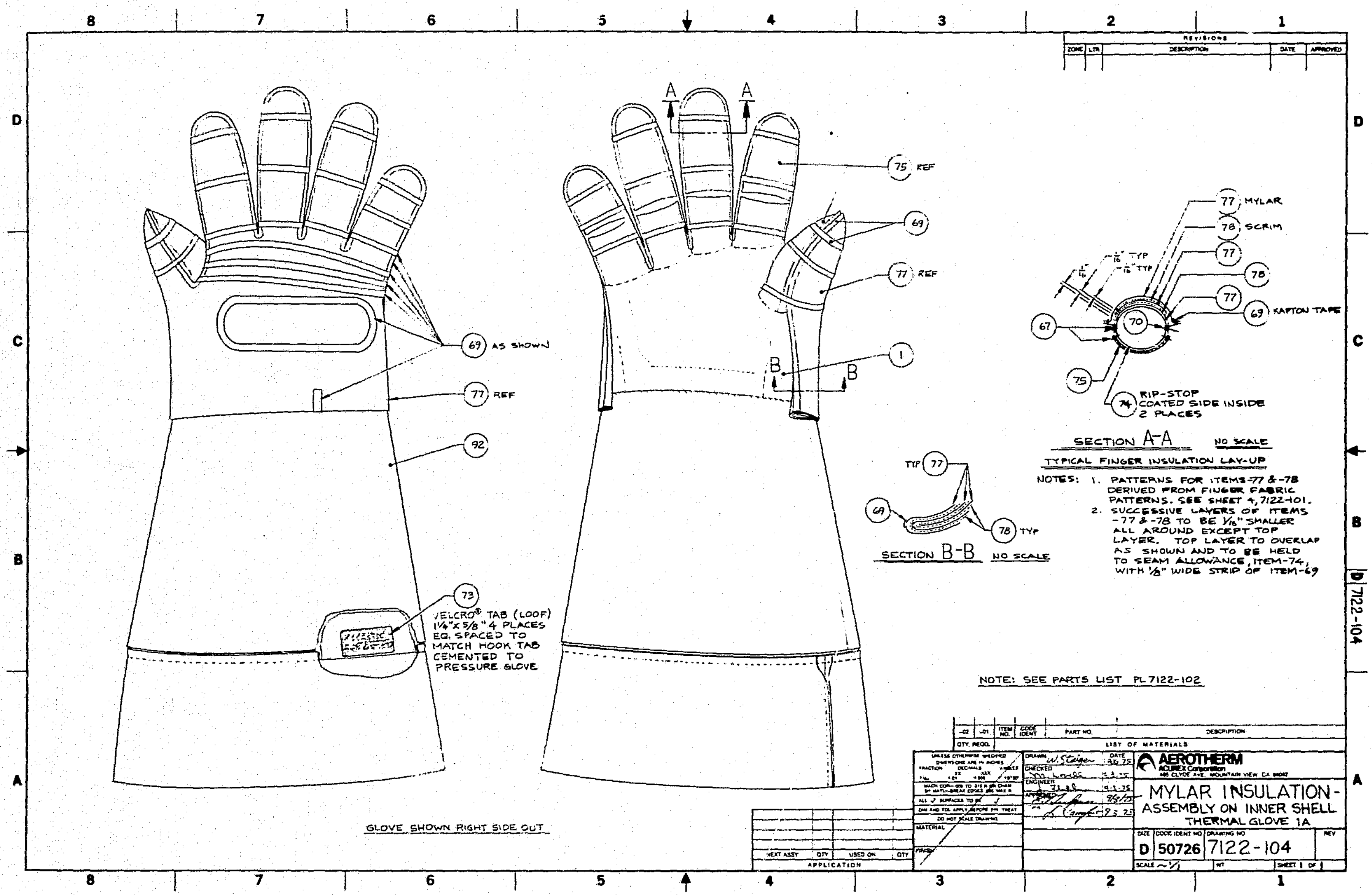
| SIZE | CODE IDENT NO | DRAWING NO | REV |
|---|---|---|---|
| D | 50726 | 7122-103 | |

SCALE | WT | SHEET 2 OF 2

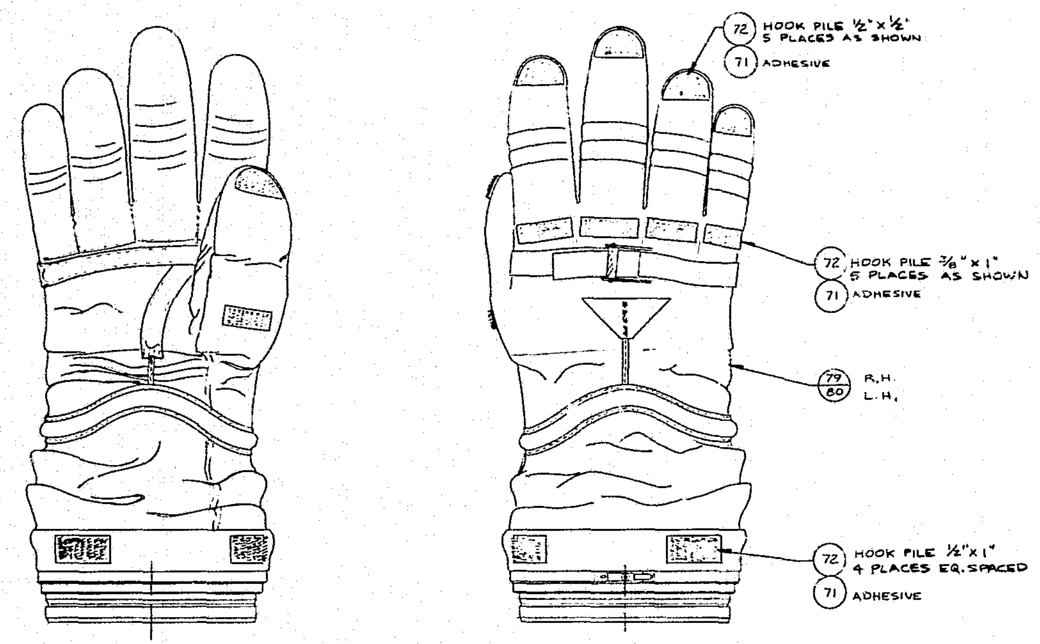
D 7122-103



NOTES:
1 SEAL SEWN AREA USING CEMENT FOR FIRE RESISTANT COATED FABRIC, USE CATALYST (TRI-MENE)
REVISIONS
ZONE
LTR
DESCRIPTION
DATE
APPROVED
R.H. 16/4
L.H. 20/4
R.H. 15/4
L.H. 19/4
17/4 R.H.
21/4 L.H.
18/4 R.H.
22/4 L.H.
R.H. 9/4
L.H. 14/4
1/8 TYP
BUTT STITCH 67
67 STANDARD MACHINE STITCH, 16 STITCHES PER INCH
BACK STITCH TO SEWING ALLOWANCE OF NEOPRENE RIP STOP. 67
OVER CAST STITCH 67
GLOVE SHOWN RIGHT SIDE OUT
46 SHOWN TURNED IN
45 SHOWN TURNED IN
43
92
1/4" (TYP)
67
7/4 R.H.
12/4 L.H.
R.H. 6/4
L.H. 11/4
8/4 R.H.
13/4 L.H.
R.H. 5/4
L.H. 10/4
MACHINE STITCH 10 ST. PER INCH
BUTT STITCH 67
CATCH STITCH 67
1/3 R.H.
2/3 L.H.
67 CATCH STITCH
67 STD. MACHINE STITCH 16 STITCHES PER INCH
NOTE: SEE PARTS LIST PL-7122-102
D 7122-101
LIST OF MATERIALS
PART NO.
DESCRIPTION
DRAWN G. LEWIS
AEROTHERM
ACUREX Corporation
INNER SHELL - SUB ASSEMBLY THERMAL GLOVE 1A
D 50726 7122-103
SCALE 1/1
SHEET 1 OF 2
7122-102-01
7122-102-02
NEXT ASSY
USED ON
APPLICATION
MATERIAL
FINISH
DO NOT SCALE DRAWING



REVISIONS
ZONE
LTR
DESCRIPTION
DATE
APPROVED
75 REF
69
77 REF
69 AS SHOWN
77 REF
92
1
B
B
A
A
77 MYLAR
78 SCRIM
77
78
77
69 KAPTON TAPE
70
67
75
74 RIP-STOP COATED SIDE INSIDE 2 PLACES
SECTION A-A NO SCALE
TYPICAL FINGER INSULATION LAY-UP
NOTES: 1. PATTERNS FOR ITEMS-77 & -78 DERIVED FROM FINGER FABRIC PATTERNS. SEE SHEET 4, 7122-101.
2. SUCCESSIVE LAYERS OF ITEMS -77 & -78 TO BE 1/16" SMALLER ALL AROUND EXCEPT TOP LAYER. TOP LAYER TO OVERLAP AS SHOWN AND TO BE HELD TO SEAM ALLOWANCE, ITEM-74, WITH 1/8" WIDE STRIP OF ITEM-69
TYP 77
69
78 TYP
SECTION B-B NO SCALE
73
VELCRO® TAB (LOOP) 1 1/4" X 5/8" 4 PLACES EQ. SPACED TO MATCH HOOK TAB CEMENTED TO PRESSURE GLOVE
NOTE: SEE PARTS LIST PL 7122-102
GLOVE SHOWN RIGHT SIDE OUT
D 7122-104
LIST OF MATERIALS
QTY. REQD.
ITEM NO.
CODE IDENT
PART NO.
DESCRIPTION
NEXT ASSY
QTY
USED ON
QTY
APPLICATION
MATERIAL
FINISH
DO NOT SCALE DRAWING
DRAWN W. Steiger
CHECKED
ENGINEER
APPROVED
AEROTHERM ACUREX Corporation
485 CLYDE AVE. MOUNTAIN VIEW CA 94042
MYLAR INSULATION-ASSEMBLY ON INNER SHELL THERMAL GLOVE 1A
SIZE D
CODE IDENT NO 50726
DRAWING NO 7122-104
REV
SCALE ~1/1
WT
SHEET 1 OF 1




NOTE: SEE PARTS LIST PL 7122-102

| -02 | -01 | ITEM NO. | CODE IDENT | PART NO. | DESCRIPTION |
|---|---|---|---|---|---|
| QTY. REQD. | | | | LIST OF MATERIALS | |

| ITEM | NEXT ASSY | QTY | USED ON | QTY |
|---|---|---|---|---|
| -80 | 7122-100-02 | 1 | | |
| -79 | 7122-100-01 | 1 | | |

APPLICATION

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
DO NOT SCALE DRAWING
MATERIAL
FINISH

DRAWN W. Staiger DATE 1 Aug 75
CHECKED 9.3.75
ENGINEER 9-3-75
APPROVED 9/3/75
9.3.75

AEROTHERM
ACUREX Corporation
485 CLYDE AVE., MOUNTAIN VIEW, CA 94042

PRESSURE GLOVE MODIFICATION
THERMAL GLOVE 1A

SIZE D CODE IDENT NO. 50726 DRAWING NO. 7122-106 REV.
SCALE 1/1 WT SHEET 1 OF 1

7122-106